Development of Compact and Low-Cost PM$_{2.5}$ Mass Concentration Measurement Equipment and Its Application to High-Frequency Mobile Monitoring in a Local Area

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Abstract. In this study, I developed a new technique that enables the measurement of the mass concentration of airborne PM$_{2.5}$ by using compact equipment and at lower cost than techniques available to date. By using this technique, I constructed a portable PM$_{2.5}$ measurement equipment that can measure concentrations with high frequency (every minute). I conducted a measurement experiment by walking along 6 km road with the measurement equipment and found that the spatial distribution of PM$_{2.5}$ is very uneven in a local area. Therefore, the local area monitoring of PM$_{2.5}$ concentration by using compact and low-cost equipment will provide better results, thus enabling us to gauge the effect of PM$_{2.5}$ on human health.

Introduction

The concentration of PM$_{2.5}$ has been measured for a long period in relation to human health. However, the number of PM$_{2.5}$ measurement stations in Japan is not sufficient at present, and the locations are concentrated within industrial areas. Therefore, it is difficult to know the ambient PM$_{2.5}$ concentration values that correspond to the daily life of citizen. From a historical reason, the amount of airborne PM$_{2.5}$ has been measured in mass concentration (ex. μg/m$^3$). Therefore, measurement equipment using a β-ray attenuation method or microbalance is widely used in measurement stations. However, this equipment is large and expensive, we cannot use this equipment in daily life easily. In order to know our surroundings well, compact and low-cost PM$_{2.5}$ measurement equipment that can measure mass concentration has long been anticipated.

I have developed a new technique that converts the number concentration (ex. counts/m$^3$) measured by a low-cost conventional light scattering PM$_{2.5}$ counter to mass concentration by a field measurement experiment. The conversion function contains humidity as a parameter. By using this conversion technique, the correlation coefficient between low-cost equipment and standard β-ray attenuation equipment is increased from 0.63 to 0.83. By this conversion, a mass concentration measurement with compact and low-cost equipment becomes actually possible.

I constructed two types of measurement equipment: one is portable, and the other is stationary. The cost is each is ca. $800, and the weight is ~1 kg. The measured data are stored in an internal flash memory.

I conducted a measurement experiment by walking along a 6 km road with the portable equipment that takes measurement every minute. The PM$_{2.5}$ mass concentration varies for a factor of four, and the spatial distribution is found to be very uneven. The concentration near the trunk road is especially high. Conducting local area monitoring using a compact and low-cost equipment will provide beneficial results in relation to human health.

Experimental

In order to differentiate between the proposed low-cost machine (=number concentration measurement) and the standard machine (=mass concentration measurement), a simultaneous measurement experiment is performed.
For a PM$_{2.5}$ mass concentration measurement, I used a β-ray attenuation type ambient air monitor PM-712 (Kimoto Electric Co. Ltd, Osaka, Japan), which is widely used in official measurement stations in Japan. Measurement interval is one hour. For a low-cost PM$_{2.5}$ counter, I use light scattering type counter DC110Pro (Dylos Corporation, CA, USA) which can be purchased for ~$500 in Japan. Measured data were logged by an SD logger (Data Techno Co. Ltd, Kyoto, Japan). Furthermore, temperature, relative humidity, and atmospheric pressure were also measured and logged by an MSR145 data logger (MSR Electronics GmbH, Switzerland).

Figure 1 illustrates the experimental settings. The measurements were taken from March to April 2014 in Kita City, Tokyo.

Results and Discussion

Comparison of Raw Data

The measured mass concentration (by PM-712) and number concentration (by DC110Pro) raw data are plotted in Figure 2a) as a function of time. The overall tendency is similar between the mass concentration and the number concentration. However, when closely observed, there is much discrepancy among both of the data. The correlation coefficient $r$ is found to be 0.63, which seems to be relatively low.

Humidity Dependence

In order to clarify the reason for the discrepancy mentioned above, I considered the influence of moisture. In Figure 3, ratio between the number concentration [counts/m$^3$] and the mass concentration [μg/m$^3$] are plotted vs. relative humidity. This plot means that the ratio is strongly dependent on relative humidity.

Malm and Day measured light-scattering functions of many types of ambient aerosols, and they received relative humidity dependence similar to Figure 3 [1]. This means that the absorption of water by aerosols changes the light-scattering behavior, and this may affect the humidity dependence of the ratio.

Conversion from the Number Concentration to the Mass Concentration

I tentatively fit the ratio data plotted in Figure 3 to hyperbolic function for convenience. The fitted line is also plotted in Figure 3. Using this hyperbolic function, I tried to convert the number concentration measured by DC110Pro to mass concentration. The result of the conversion is plotted in Figure 2b). The calculated mass concentration and the authentic (= measured by PM-712) mass concentration are in good agreement. The correlation coefficient $r$ between the two mass concentrations is found to be 0.82, which is drastically improved from the value before the conversion.
I successfully measured the mass concentration by using a low-cost PM$_{2.5}$ counter and data conversion based on a humidity-dependent function.

![Graph showing mass concentration and number concentration](image)

**Figure 2.** a) Raw data of authentic mass concentration and the number concentration by low-cost machines. b) The number concentration data by low-cost machine is converted to mass concentration.

![Graph showing ratio vs. relative humidity](image)

**Figure 3.** Ratio of the number concentration to mass concentration is plotted vs. relative humidity (the filled circle). A fitted hyperbolic line is also plotted.

**Development of the Compact Measurement Equipment**

Based on the data conversion technique mentioned above, I constructed two types of compact PM$_{2.5}$ measurement equipment that can measure mass concentration. One is stationary, which is suitable for indoor use, and the other is portable. The cost of each is *ca.* $800, and the weight is ~1 kg. The measured data are stored in an internal flash memory.

Figure 4 shows the stationary equipment.
The Mobile Measurement Experiment

By using the portable equipment mentioned above and a GPS logger, I conducted a measurement experiment by walking along a 6 km road in Kanagawa Prefecture Japan and took a measurement every minute. The result is depicted in Figure 5. The measurement point is indicated by the position of the bottom end of the bar, and the mass concentration is indicated by the length and color of the bar. The bars are superimposed on topographical map.

On viewing this figure, the ratio between the maximum and minimum concentration is proved as four: the PM$_{2.5}$ spatial distribution is found to be very uneven.

In addition, the concentration near the trunk road is found to be especially high. In Figure 5, the national road runs through this area (indicated by crosses), and the maximum concentration is found near this road. This observation may be ascribed to the exhaust gas emitted from cars traveling on this road.

Summary

To date, a mobile or high-frequency measurement of PM$_{2.5}$ mass concentration was almost impossible because of technical limitations. In this work, I successfully measured PM$_{2.5}$ mass concentration using a compact equipment with high-frequency.
Local area monitoring of the PM$_{2.5}$ concentration is very important from the viewpoint of human health, and this technique will be effective for such monitoring.

Reference

[1] W. C. Malm, D. E. Day. Estimates of aerosol species scattering characteristics as a function of relative humidity, Atmospheric Environment 35 (2001) 2845-2860.