

A Study on Real-Time Water Droplets Removal Techniques with Two-Wavelength Scanning LiDAR Monitoring

Yuseon Lee^(a), Dukhyeon Kim^(a), Juhyeon Sim^(c), Gahyeon Park^(d), Youngmin Noh^(e)

(a) Pukyong National University, Division of Earth Environmental System Science, Environmental Engineering, E-mail : yslee0824@pukyong.ac.kr

(b) School of Basic Science, Hanbat National University, Daejeon 34158, Korea, E-mail : dhkim@hanmail.net

(c) Pukyong National University, Division of Earth Environmental System Science, Environmental Engineering, E-mail : sjh10120901@pukyong.ac.kr

(d) Pukyong National University, Division of Earth Environmental System Science, Environmental Engineering, E-mail : hyeon20522@naver.com

(e) Pukyong National University, Division of Earth Environmental System Science, Environmental Engineering, E-mail : nym@pknu.ac.kr

Abstract: This study focuses on the technology for real-time water droplets removal using two-wavelength scanning LiDAR monitoring. The LiDAR measures the Ångström exponent, using extinction coefficients at 1064 nm and 532 nm wavelengths, to assess particle size, and calculates depolarization ratio from backscatter signals at 532 nm to determine particle shape. This technology allowed for the identification and classification of particle types, focusing on fine particles while excluding water droplets. The aim of this study is to use scanning LiDAR to distinguish fine particles and water droplets across a wide area and to identify their movement and origin when pollutant concentrations are high.

1. Introduction

As societal concern over fine particles grows, the importance of accurately identifying and managing emission sources is increasingly emphasized. Currently, the government conducts fine particles measurements using site observation equipment such as the Chimney Automatic Measurement System (TMS), but there are limitations in tracking the source, movement, and dispersion of emissions. Hence, active remote monitoring systems using LiDAR (Light Detection and Ranging) technology have emerged as a new alternative[1,2]. This study utilizes a self-developed Scanning LiDAR system to differentiate particles using the Ångström exponent, calculated from the ratio of extinction coefficient at two wavelengths, and the depolarization ratio, derived from vertical and horizontal backscatter signals. This approach allows for precise, real-time identification of fine particles emission sources in ports and industrial areas, while also accurately visualizing their concentration distribution. The study aims to provide a more accurate visualization of fine particles concentration distribution by addressing issues

caused by unstable signals through improvements in the data analysis algorithm.

2. Method

2.1. Measurement site and Instrument

In this study, the utilized Scanning LiDAR is a remote optical monitoring device that operates at two wavelengths, 532 nm, and 1064 nm, featuring an angular resolution within 20° and capable of observing 360° within 30 minutes. This equipment enables real-time and continuous concentration measurements of PM₁₀ and PM_{2.5}. It emits light at the two specified wavelengths using an Nd:YAG laser and the beam splitter and expander adjust the light to detect scattered light caused by particles in the atmosphere[3]. The detected light is then divided into three channels by a telescope and converted into electrical signals.

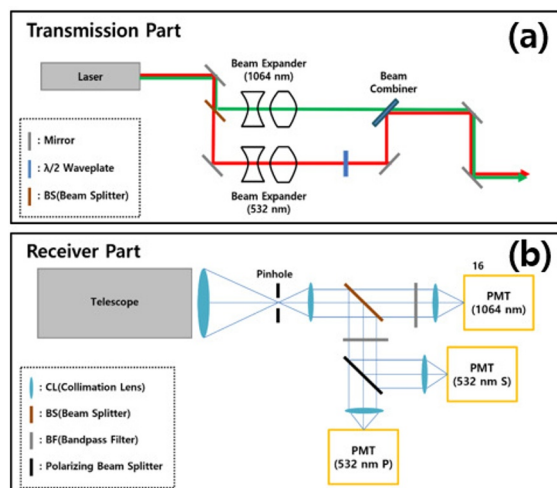


Figure 1. Scanning LiDAR transmitter(a), receiver(b)

This system was installed on the rooftop of the Dangjin Port Support Center in Dangjin City, Chungcheongnam-do(36°59'07.7"N 126°44'44.2"E). Observations were conducted a total of 1,526 times over 38 days, from February 16 to March 29, 2022, covering various angles.

2.2. Angstrom Exponent

The Ångström Exponent is a parameter indicating the optical characteristics related to the size of aerosol particles[4,5], calculated through the logarithmic ratio of extinction coefficient measured at two wavelengths (532 nm and 1064 nm). The Ångström Exponent value close to 0 signifies the presence of larger particles, while a value of 2 or higher indicates a predominance of smaller particles[6].

$$AE(r) = -\frac{\ln[(\alpha_a(\lambda_{1064}, r))/(\alpha_a(\lambda_{532}, r))]}{\ln(\lambda_{1064}/\lambda_{532})} \quad (1)$$

Applying the method for calculating the extinction coefficient at 532 nm directly to 1064 nm has been found to result in inaccuracies due to the lower extinction efficiency at 1064 nm, leading to instability in the Ångström Exponent. Consequently, this study aims to correct the calculation of the extinction coefficient at 1064 nm by utilizing the relationship between the PM_{2.5} ratio and the theoretical Ångström exponent, as outlined in the following flowchart.

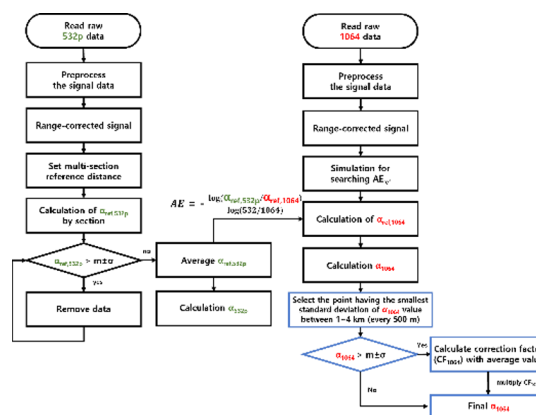


Figure 2. Correction method for calculating extinction coefficients at 532 nm and 1064 nm

2.3. Correction method for calculating the extinction coefficient at 1064 nm

The method for calculating the extinction coefficient involves multiplying the particle's extinction efficiency by its volume size distribution and then integrating the result. The extinction efficiency is determined for particle diameters of 10 μm and 2.5 μm at the 1064 nm wavelength.

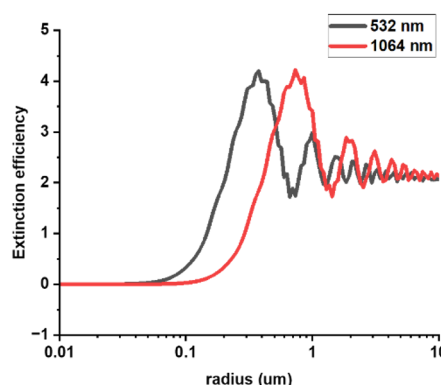


Figure 3. Extinction coefficient by wavelength according to particle diameter

The volume size distribution of fine particle is defined by six parameters: the total volume of coarse and fine particles, central size, and distribution width. The PM_{2.5} ratio can be calculated by integrating each volume value and then multiplying by the density.

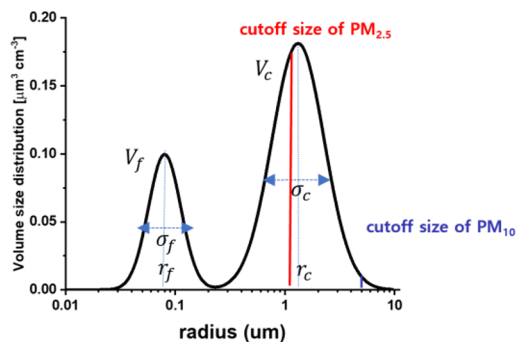


Figure 4. Volume size distribution according to particle diameter

Subsequently, the relationship between the theoretical Ångström exponent and the PM_{2.5} ratio is represented graphically using 1000 random numbers.

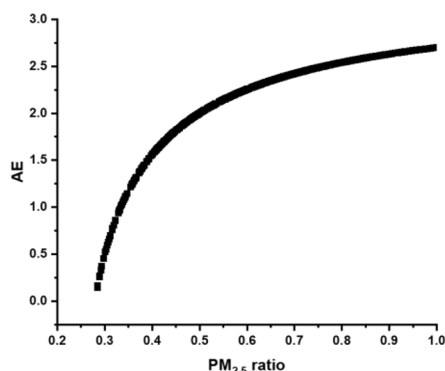


Figure 5. Theoretical AE simulation depending on PM_{2.5} ratio

PM_{2.5} and PM₁₀ data corresponding to the observation time are obtained from AirKorea to calculate the theoretical Ångström exponent, after which the extinction coefficient at 1064 nm is corrected using the Klett equation. During this process, underestimations or overestimations at specific angles were identified, and additional corrections to the data baseline were conducted. Among the points set at 500 m intervals between 1 km and 4 km, the value with the smallest standard deviation of the extinction coefficient was selected. The final α_{ref} is derived by applying a correction factor based on the average and standard deviation of that point.

2.4. Depolarization ratio

The Depolarization Ratio(DP) is used as an indicator of the non-sphericity of aerosol particles in the atmosphere. For spherical particles, the DP value is close to 0, while for

non-spherical particles, the DP value is higher due to backscatter occurring in various directions[7,8]. This value is calculated from the ratio of vertical(P_s) to horizontal(P_p) backscatter signals measured at a wavelength of 532 nm[9].

$$\delta = \frac{P_s}{P_p + P_s} \quad (2)$$

When calculating the depolarization ratio using the conventional method, instances occurred where the depolarization ratio of background atmospheric aerosols was overestimated due to weak S signals. To correct this, a correction factor was applied by dividing the average depolarization ratio from 1 km to 3 km by the average atmospheric aerosol depolarization ratio of 0.03, to calculate the final depolarization ratio. The specific process is shown in Figure 6.

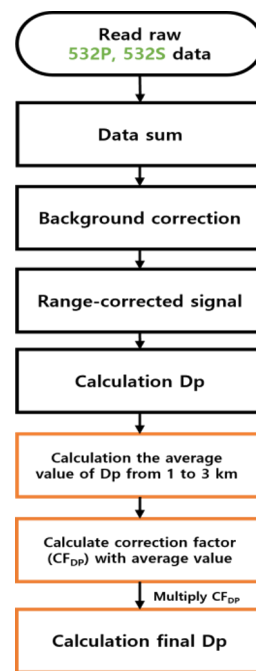


Figure 6. Depolarization ratio flowchart

3. Result

The correction process resulted in a reduced standard deviation of the Ångström exponent, and by correcting the extinction coefficient at 1064 nm, the baseline of the Ångström Exponent was stabilized. Before the correction, the baseline of the depolarization ratio varied with each observation, but after the correction, the baseline of the depolarization ratio was consistently adjusted to 0.03.

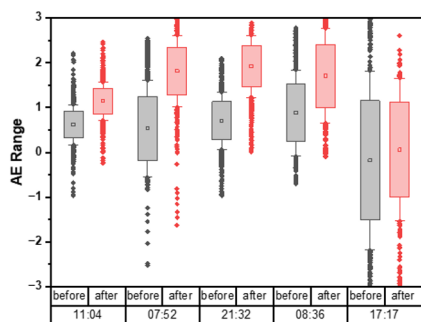


Figure 7. Data analysis overall Angström exponent results

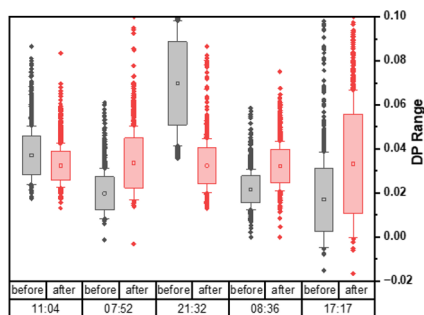


Figure 8. Data analysis overall depolarization ratio results

The profile analysis showed a decrease in the Ångström exponent without significant changes in the depolarization ratio, indicating that most particles are large and spherical, namely water droplets. Through the analysis of water droplet particles, it was determined that cases with an Ångström exponent below -0.1 and a depolarization ratio under 0.7 are classified as water droplets. As demonstrated in Figure 8, cases of high-concentration water droplets were successfully identified and removed.

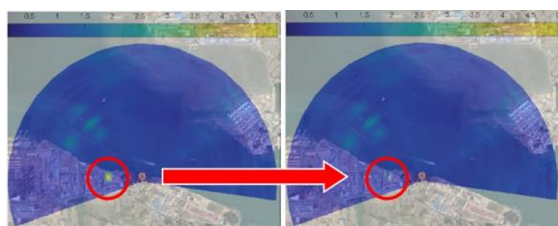


Figure 8. Removal of water droplets during visualization

4. Conclusion

In this study, Scanning LiDAR was utilized to observe fine particles in the atmosphere over a specific period, and through the analysis of the Ångström exponent and depolarization ratio, fine particles and water droplets were differentiated, with water droplet particles being removed for visualization. The correction process addressed issues with the extinction

coefficient at 1064 nm and the baseline of the depolarization ratio, and it is anticipated that distinguishing particle types will positively impact the enhancement of air pollution monitoring systems.

5. Acknowledgement

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6. References

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