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Overlapping Coefficient Correction for Multi-Wavelength Polarization Lidar

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***Abstract*—Geometric overlapping coefficient is one of the key factors for the near distance signal processing in lidar detection field. Based on the geometric analysis of Mie-polarization lidar, three kinds of shape of the overlapping area of between the telescope field of view and the laser of an off-axis Mie-polarization lidar in close range was discussed and studied. The overlapping nalytical formula for the off-axis lidar overlapping coefficieints was preseneted. Finally, based on the analytical formula and the Gauss distribution of the laser beam, the varying curve of the overlapping coefficieint of the multi-wavelength polarization scattering Lidar was obtained and discussed. According to the experiment results, the geometrical overlapping coefficient distribution along with distance is relative stable under condition of proper operation. But after long distance transportation or adjustment of lidar architecture, the geometrical overlapping coefficient should be obtained through field experiment.**

Keywords*—*depolarization; multl-wavelength; lidar; overlapping coefficient

I. INTRODUCTION

Mie-polarization lidar has been successfully applied in the measurement fields of scattering materials of liquid and gas phase in the atmosphere[1]. Lidar is characterized with extremely high distance resolution, high sensitivity, is a powerful tool to detect and interrogating the back-scattering and polarization information of biological agents/aerosol. The obtained multi-wavelength polarization data can be used to reveal some useful characteristics of bioagents/bioaerosols.

When the Mie-polarization scattering technology was used to detect the depolarization ratio at wavelengths of 355nm, 532nm and 1064nm and the vertical profile of extinction coefficient of atmospheric aerosol in the whole troposphere, the dynamic range of atmospheric echo signal reaches up to about 8 orders of magnitude[2], furthermore, the atmospheric echo signal within the atmospheric boundary layer is even stronger then that in the tropospheric layer. So, the reasonable solution is the usage of the design of bi-axial lidar system and appropriate geometrical overlapping coefficient to meet the detection requirement of atmospheric echo signal in the whole troposphere within a large dynamic range, and two detectors in different channel are used simultaneously to detect the backscattering echo signal in upper and lower atmospheric layer.

II. SCHEME OF MIE-POLARIZATION LIDAR

The lidar was equipped with the Quantel Briliant B Nd:YAG laser with a 100Hz repetition frequency, the pulse energy was 200 mJ, 40mJ and 80 mJ at the fundamental frequency wavelength 1064 nm, 3rd harmonic frequency wavelength 355 nm, and double frequency wavelength 532nm. The laser beam of 2cm diameter was generated by the beam expander, the divergence angle was 0.5-mrad, so more than 80% laser energy within the laser beam was used for outputting and detection. The 1/500 linear polarization purity of laser beam was generated by a polarizer cube and then emitted by a scanning optical system. Through a λ/2 wave plate, the vertical linear polarization can be converted to the horizontal linear polarization, and the vertical linear polarization can be converted to the right circular polarization or left circular polarization through λ/4 wave plate. Figure 1 showed the principle diagram of multi-wavelength Mie-polarization lidar system and its debugging snapshot in the lab.

The optical receiving system included an off-axis parabolic mirror with a diameter of 200mm and focal distance of 760mm. The reflectivities of primary mirror and scanning mirror were different at directions parallel and vertical to the incident polarization, and compensated individually. The mirrors of 1064 and 1570nm were gold coated, and the 355 and 532nm mirrors were coated with aluminum.

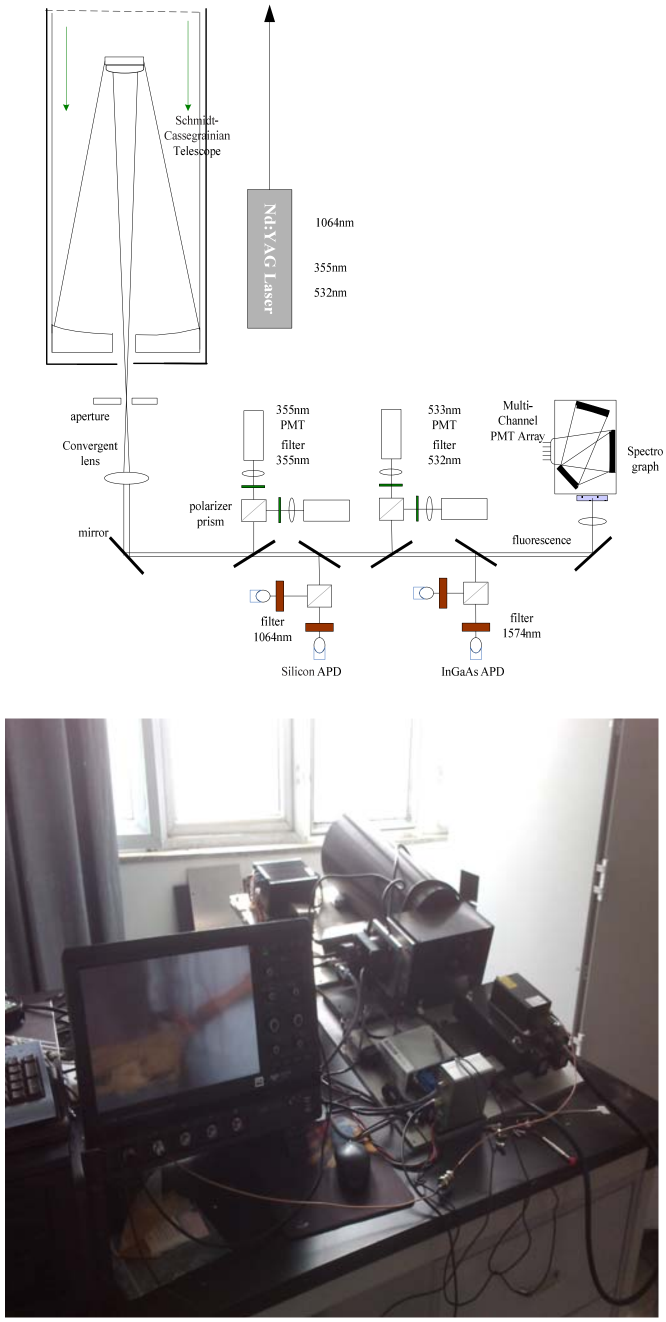

Fig. 1. Multi-wavelength polarization lidar system and debugging in the lab.

III. PRINCIPLE OF OVERLAPPING COEFFICIENT

The geometrical overlapping coefficient of parallel-axis lidar system was shown in Figure 2. Physically, geometrical overlapping coefficient is defined as the ratio of the section area of beam received by receiver telescope on the section at the distance of *R*, to the whole beam area. As shown in Figure 2, when $R \le R_1$, $\eta(R)=0$, then this region was called as bind region of detection, as well as R_1 was called as the distance of blind region, hence, there was no atmospheric echo signal of laser within this region. When $R_1 < R < R_2$, $0 < \eta(R) < 1$, the region was called transition region. Within this transition region, part of echo signals enter the receiver telescope, so the effective utilization of laser energy gradually increased with the distance. In case of $R \ge R_2$, $\eta(R)=1$, so this region was called as full region. The backscattering energy of laser beam was fully utilized, and R_2 was called as the distance of full region. Therefore, it is necessary to correct the geometrical overlapping coefficient when aerosol measurement data is processed, it meas that the lidar echo within transition region must be normalized until the entire atmospheric echo signal was collected as $\eta(R)=1$.

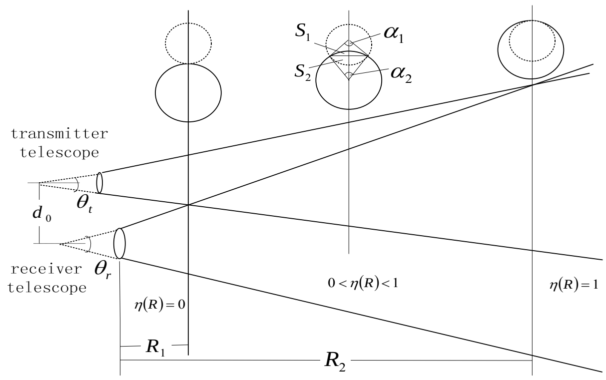

Fig. 2. Principle of geometrical overlapping coefficient of parallel axis lidar.

Ideally, the intensity of each point in the beam distributed evenly, and the diameters of transmitter telescope and receiver telescope were D_t and D_r respectively, the distance between two optical axes was d_0, the divergence angle of laser beam plane and the angle of receiving FOV plane were θ_t and θ_r, so through the geometrical layout, the section radius r_1 of transmitting beam and section radius r_2 of receiving beam can be defined as,

$$r_1 = \frac{D_r + \theta_r R}{2}$$

$$r_2 = \frac{D_t + \theta_t R}{2} \tag{1}$$

Where, the blind region distance R_1 and full region distance R_2 was also expressed as,

$$R_1 = \frac{d_0 - (D_r + D_t)}{\theta_r + \theta_t}$$

$$R_2 = \frac{d_0 - (D_r - D_t)}{\theta_r - \theta_t} \tag{2}$$

Then, it can be known that the larger the receiving field angle θ_r was, the shorter distance of R_1 and R_2 can be engaged, and the lesser influence of geometrical overlapping coefficient on the lidar distance was engaged, but the background radiation noise was much more stronger, so, the optimum matching of θ_t and θ_r needed to be comprehensively considered, generally, the receiving field angle θ_r was slightly larger than the divergence angle of laser beam.

Assuming that the laser intensity distributed evenly and two optical axes were parallel, the geometrical overlapping coefficient can be obtained through the geometrical relationship in Figure 2, and expressed as follows,

$$\eta(R)=\frac{s_1+s_2}{\pi r_1^2}=\frac{r_2^2(\alpha_2-\sin\alpha_2)+r_1^2(\alpha_1-\sin\alpha_1)}{2\pi r_1^2} \tag{3}$$

Where, s_1 and s_2 referred to two arch areas of section within overlapping region from transmitting laser beam and the receiving echo beam respectively, and α_1 and α_2 were the corresponding central angles of s_1 and s_2, respectively, as shown in Figure 2. It was proved by previous experiments that[3] if there was a certain angle between two optical axes, there will change the geometrical overlapping coefficient seriously, when the angle reaches up to ±0.1mrad, more than 5% error would be generated. Hence, the collimation of system should be maintained, and the mis-alignment error should be less than ±0.1mrad.

IV. EXPERIMENTS OF GEOMETRICAL OVERLAPPING COEFFICIENT

As was mentioned early, due to the uncertainty of lidar system parameters (divergence angle of lidar, collimation degree of optical system, and so on), and the lidar structure and assembling state can not be stable during the transportation processes and adjustment, so it was not realistic to obtain the geometrical overlapping profile by equation (3), thus generally, obtained by experiments.

Under the condition of homogeneous atmosphere, the extinction coefficient of atmosphere σ_R equals to σ_0 and then is a constant, as well as the atmospheric back-scattering coefficient was β_R equals to β_0 and then was also a constant. Hence, the geometrical overlapping coefficient of lidar can be obtained by lidar equation,

$$\eta(R)=\frac{P(R)R^2\exp(2\sigma_0 R)}{C\beta_0} \tag{4}$$

If $R'>R_2$, as shown in Figure 1, then $\eta(R')=1$, and equation (4) is given,

$$1=\frac{P(R')R'^2\exp(2\sigma_0 R')}{C\beta_0} \tag{5}$$

Then, the geometrical overlapping coefficient can be expressed by dividing equation (5) by equation (4).

$$\eta(R)=\frac{P(R)R^2\exp(2\sigma_0 R)}{P(R')R'^2\exp(2\sigma_0 R')} \tag{6}$$

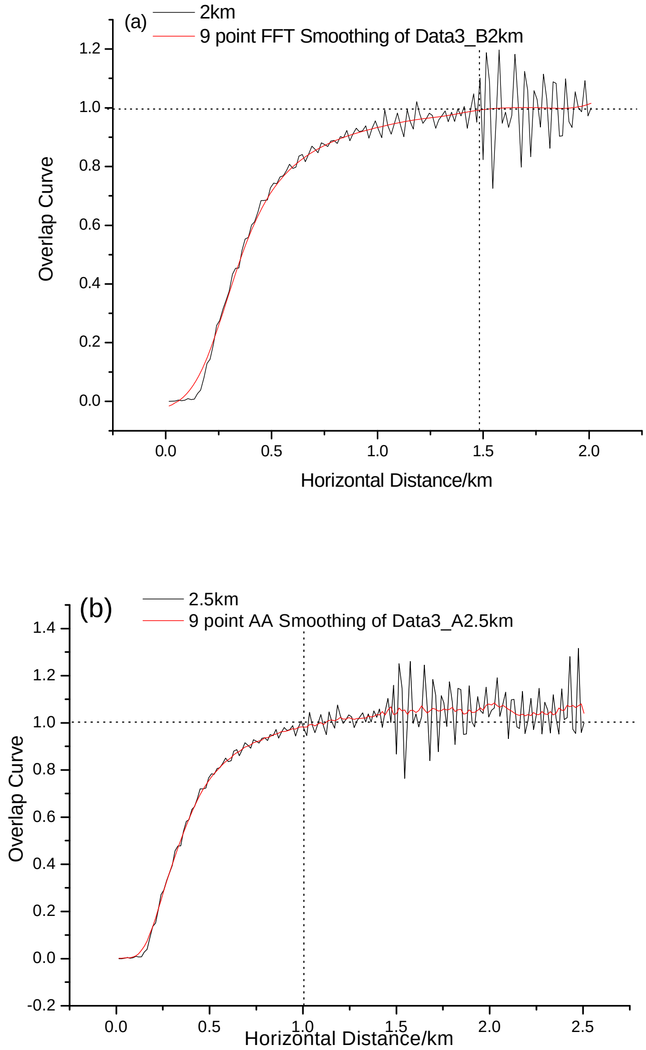

Fig. 3. Experiment results of geometrical overlapping coefficient profile of Mie-polarization lidar (a:R′=2.0km, b: R′=2.5km).

Figures 3(a) and (b) showed the overlapping coefficient profiles of Mie-polarization lidar obtained from the measured data at 15:15 on March 13, 2016.

Obviously, the lidar echo signal enters fully the field of view of telescope at a distance around of 1km, so the full region distance R_2 of lidar was about 1.0km. This distance was larger than the full region distance R_2 (400m) of L300 lidar and was slightly different from the full region distance (R_2 = 1.0km) of AML-1 lidar, but it was smaller than the transition region distance($R2\approx4$km) of MPL.

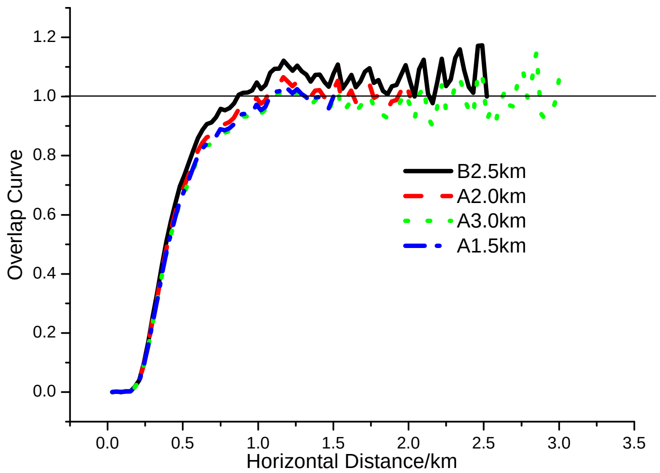

Fig. 4. Experiment results of geometrical overlapping coefficient profile of polarization lidar.

Figure 4 showed the geometrical overlapping coefficient profile of Mie-polarization lidar after PMT voltage adjustment on April 20, 2016. Clearly, overlapping coefficient rises to 1.0 at a distance of about 1.0km, so the full region distance R_2 was about 1.0km. However, there existed some oscillation at a distance far more than 1.0km, oscillation of overlapping coefficient curve was caused by inhomogeneous atmosphere within this distance.

V. CONCLUSIONS

For application of Mie-polarization lidar, the geometrical overlapping coefficient was a double-edged sword. Firstly, the lidar signal within the geometrical overlapping region needed to be corrected with geometrical overlapping coefficient, but it is doomed that, errors from the lidar echo correction by geometrical overlapping coefficient will be generated. But on the other hand, the dynamic range of lidar echo could be reduced through design of lidar, as well as with the appropriate geometrical overlapping coefficient.

According to the experiment results, the geometrical overlapping coefficient distribution along with distance is relative stable under condition of proper operation. But after long distance transportation or adjustment of lidar architecture, the geometrical overlapping coefficient should be obtained through field experiment.

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