The signal correction of a CW-laser-outgoing Helium Lidar based on an area-array ICCD

Ruocan Zhao[1], Xianghui Xue[2], Dongsong Sun[1], Jiaxin Lan[1], Tingyu Pan[1], and Xiankang Dou[3]

[1]University of Science and Technology of China
[2]Univ. of Sci.& Tech. of China
[3]USTC University of Science and Technology of China

November 24, 2022

Abstract

A Helium Lidar system, which is being developed for measurements of metastable helium density in the thermosphere and exosphere, employs a CW 1083nm laser with power of 60W, a telescope array consisting of six 1m-diameter telescope and an area-array ICCD. To realize range-resolved remote sensing, the laser is located separately from the location of telescope with a distance of D and the laser beamed is leaned towards the Field-of-view (FOV) of the telescope array with an zenith angle of ϑ. The signal in a specific height is finally imaged onto a corresponding pixel of the ICCD. Before the retrieval of metastable helium density, the first procedure is to decide the relation between the pixels and corresponding heights. Based on the FOV of the telescope, the divergence angle of the laser beam, the geometry of the laser and telescope, and the size of the pixels, every pixel corresponds to a specific height range, as shown in Fig. 1. The darkest shade corresponds to one pixel of the ICCD. Therefore, the second procedure is to correct the height range overlap of the signal from adjacent pixels to decrease the smoothness of the signal profile caused by the height overlap of adjacent pixels. The signal received by the ICCD is simulated based on a metastable helium density model developed by Waldrop et. al. The results show that these two signal correcting procedures can improve the precision of each pixel's signal by 5% in average.

Posted on 24 Nov 2022 — CC-BY 4.0 — https://doi.org/10.1002/essoar.10500560.1 — This a preprint and has not been peer reviewed. Data may be preliminary.

The signal correction of a CW-laser-outgoing Helium Lidar based on an area-array ICCD

中国科学技术大学

Ruocan Zhao[1], Dongsong Sun[1], Xianghui Xue[*,1], Jiaxin Lan[1], Tingyu Pan[1], and Xiankang Dou[1]
1. University of Science and Technology of China, Hefei, Anhui, China

ABSTRACT

A Helium Lidar system, which is being developed for measurements of metastable helium density in the thermosphere and exosphere, employs a CW 1083nm laser with power of 60W, a telescope array consisting of six 1m-diameter telescope and an area-array ICCD. To realize range-resolved remote sensing, the laser is located separately from the location of telescope with a distance of D and the laser beam is leaned towards the Field-of-view (FOV) of the telescope array with an zenith angle of φ. The signal in a specific height is finally imaged onto a corresponding pixel of the ICCD. Before the retrieval of metastable helium density, the first procedure is to decide the relation between the pixels and corresponding heights. Based on the FOV of the telescope, the divergence angle of the laser beam, the geometry of the laser and telescope, and the size of the pixels, every pixel corresponds to a specific height range, as shown in Fig. 2. Therefore, the second procedure is to correct the height range overlap of the signal from adjacent pixels to decrease the smoothness of the signal profile caused by the height overlap of adjacent pixels.

HELIUM LIDAR SYSTEM

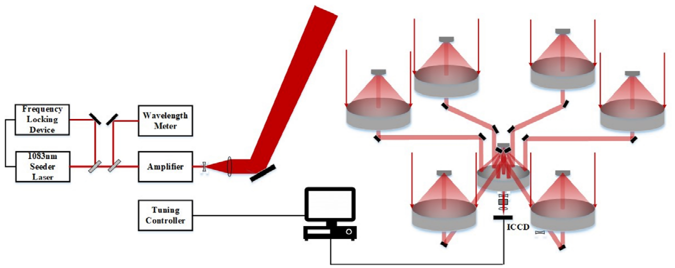


Figure 1 The Schematic diagram of Helium Lidar System

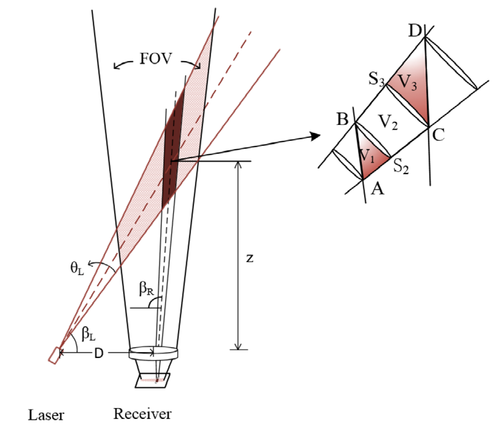
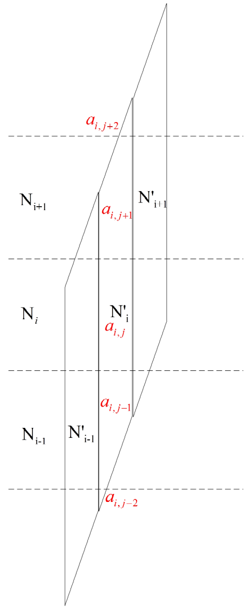


Figure 2 The geometry of the laser beam and the telescope. The darkest shade corresponds to one pixel of the ICCD.

SIGNAL CORRECTION



Laser beam elevation	1.566 *rad*
Laser beam divergence	50 *μrad*
Telescope FOV	0.5*mrad*
Transmit-receive distance	1.6km

The geometric setup of this CW-imaging lidar is decided by four parameters shown in the table above. The volumes corresponding each pixels is very large in height but short in horizontal. Besides, the central height difference of adjacent volumes is much smaller than the vertical length of the volumes. Which means, the signal received by the ICCD' s pixels is a smoothed curve with a averaging gate of the volume vertical length and a stepping length equal to the distance of adjacent volumes' s central height.

As shown in the figure above, N represents the actual signal of unit volume in the layers separated by the dashed lines. The dashed lines are the central height of adjacent volumes. N' is the signal received by the iCCD pixels. Every volumes are separated by the dashed lines into different parts, represented by a. Therefore, the ith volume' s signal can be represented by a and N:

$$N'_i = \sum_{j=1...m} a_{i,j} N_{i+j-m/2}$$

The relation between the iCCD signal N' and the un-smoothed signal N can be written as:

$$\underset{\uparrow \atop A}{\begin{pmatrix} a_{11} & \cdots & a_{nn} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}} \cdot \underset{\uparrow \atop N}{\begin{pmatrix} N_1 \\ \vdots \\ N_n \end{pmatrix}} = \underset{\uparrow \atop N'}{\begin{pmatrix} N'_1 \\ \vdots \\ N'_n \end{pmatrix}}$$

Therefore, the un-smoothed (or corrected) signal can be retrieved from the iCCD signal using the inverse matrix of A. Matrix A can be calculated at the beginning from the geometric setup of the system.

$$N = A^{-1} \cdot N'$$

LIDAR EQUATION

$$N_S(n) = \frac{P_L \tau}{hc/\lambda_0} \cdot \frac{V(n) \cdot A}{\pi (\tan\frac{\theta_L}{2})^2 \left(\frac{z(n)}{\sin\beta_L}\right)^2 \left(\frac{z(n)}{\sin\beta_R}\right)^2} \cdot \left(N_C \frac{\sigma_{eff}}{4\pi} R_B\right) \cdot \eta T^2 E(z)^2 + N_B \tau$$

- P_L laser power
- τ accumulating time
- h planck constant
- c speed light
- λ_0 Laser wavelength
- $\rho_c(z)$ Metastable helium density
- σ_{eff} Effective cross section
- R_B Branching ratio
- A_R Area of telescope
- η Total receiving efficiency
- T One-way atmosphere Transmission
- E(z) Extinction coefficient
- $z(n)$ Height
- θ_L Laser beam divergence
- β_L Laser elevation
- $\beta_R(n)$ Elevation of nth volume to the telescope
- V(n) Volume of the nth overlap of the laser and pixel.
- N_B Background noise and dark count

CONCLUSION

This poster mainly shows the basic system design of a CW-imaging helium density lidar and the iCCD signal correction method. The reason of choosing a CW laser is a pulsed 1083nm laser has limited low power. The accuracy of the signal correction depends on the accuracy of the lidar' s geometry. The lidar is under developing now in University of Science and technology of China, which would be probably the first helium lidar measuring metastable helium density between 200km and 1000km. Now, we are still investigating the best geometric setup of the system which will taking the biggest advantages of the laser power and the telescopes and will achieve the best signal-noise-ratio.

CONTACT

Xianghui Xue: Xuexh@ustc.edu.cn
Ruocan Zhao: canlan@ustc.edu.cn
Jinzhai Rd 96, University of Science and Tech. of China
Baohe District,Hefei, Anhui, 230026,CHINA