Journal of Marine Science and Technology; Vol. 17, No. 4B; 2017: 51-57
DOI: 10.15625/1859-3097/17/4B/12991
http://www.vjs.ac.vn/index.php/jmst

THE SIMULATION OF AEROSOL LIDAR DEVELOPED AT THE INSTITUTE OF GEOPHYSICS

A. D. Tuan[1], N. X. Anh[2*], T. P. Hung[2]

[1]*Institute of Applied Physics and Scientific Instrument, VAST*
[2]*Institute of Geophysics, VAST*
[*]E-mail: nxuananh05@gmail.com

Received: 9-11-2017

ABSTRACT: Lidar is an active remote-sensing system that uses laser radiation in the ultraviolet, visible and near-infrared wavelength domain. It allows the measurement of the physical properties of the atmosphere with spatial and temporal resolution. We have simulated the system and researched the initial design of the Lidar system to monitor the aerosol with the main parameters: high power Nd - YAG pulse laser emitted at the 532 nm wavelength. The system includes 28 cm diameter optical glass, photomultiplier tube (PMT) - H6780-03 photodetector, and optical components for convergence and filtering of reflected reflections. Initial measurements show that the Lidar system is highly sensitive, which determines important atmospheric properties such as the distribution and physical properties of the aerosol and height of ABL (atmospheric boundary layer).

Keywords: Lidar, simulation, aerosol, ABL.

INTRODUCTION

The Lidar system (Light Detection and Ranging) is used extensively in atmospheric research. It can measure atmospheric density and temperature according to height, a study of equatorial stratigraphic cloud, equatorial stratigraphy, stratospheric stratosphere, stratified and tropospheric air, atmospheric boundary layer, vapor velocity, motion disturbance, and other atmospheric gases [1-10]. In some developed countries, a national, regional and international Lidar network has been formed, such as EARLINET (Europe Lidar Network), MPLNET (Micropulse Lidar Network), CIS - Linet - Network. In Vietnam, the Vietnam Academy of Science and Technology and Military Technical Academy has been designing, manufacturing and developing Lidar systems for atmospheric monitoring [1-3]. The Ministry of Natural Resources and Environment currently uses the Lidar system on unmanned aerial vehicles (UAVs) for resource management and use.

Studying the Lidar system, we found that the lidar system was very complex and highly dependent on the subject matter studied. So, researchers, designers, and manufacturers must have comprehensive expertise in the fields of quantum mechanics, physics, electronic engineering, programming and signal processing.

Recent studies have shown that the mathematical modeling of lidar systems and signals along with the increased resolution of the lidar system can help significantly improve aerosol and wind studies [11, 12]. To comprehensively study the lidar system, we have built a simulation program. Simulation objects include system hardware and study objects. This simulation is important and necessary in the research and design of the equipment. It helps to select the appropriate hardware parameters for research purposes (aerosol) and is the basis for the processing and interpretation of obtained data [13]. In this article, as reported in the National Conference on Electronic Communications and Information Technology REV - 2016 [14], we present some of the results of research into the design, manufacture, and refinement of lidar system using system simulation software.

LIDAR SYSTEM DESIGN METHOD

Theoretical basis

Most of atmospheric lidar systems have the same structure as shown in fig. 1, which consists of four main components: Laser transmitter; Telescope optical receiver; Detection optics and filter; Electronic data collection, analysis, data processing and system control [4-7].

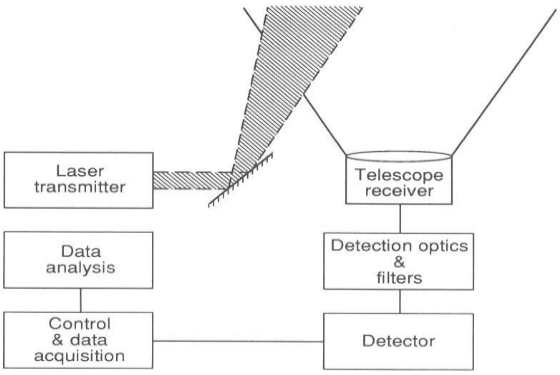

Fig. 1. Lidar system block diagram

The lidar equation expresses the relationship between the amount of photon emitted by the laser (laser energy emitted) and the amount of photon absorbed (laser energy scattering feedback). Laser light is transmitted in the atmosphere or other objects and there is a physical interaction between the laser light and the object (fig. 2).

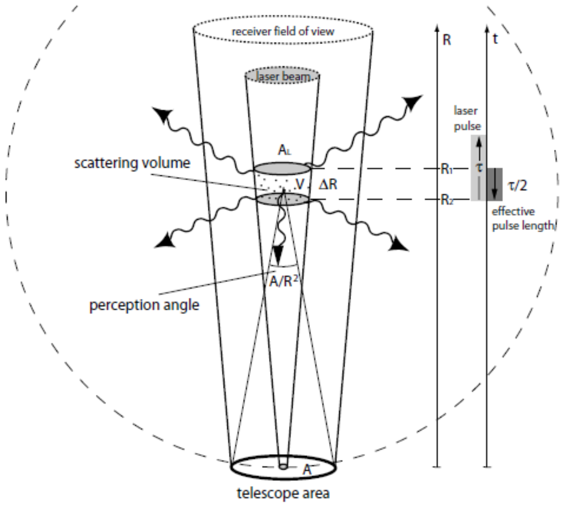

Fig. 2. Lidar equation

The lidar equation is developed under two assumptions: The scattering process is independent and only single scattering. Independent scattering means that the elements are isolated and randomized so that the contribution to total energy scattered by many elements has no phase relationship, so the total scattering intensity is simply the total scattering intensity from each element. Single scattering is a photon scattered only and multiple scattering is not considered.

The lidar equation describes the mathematical model of physical processes that take place in the atmosphere when exposed to laser light. The lidar equation has the general form as bellow [4-7, 15]:

$$N_S(\lambda,R)=N_L(\lambda_L).[\beta(\lambda,\lambda_L,\theta,R)\Delta R].A/R^2.[T(\lambda_L,R)T(\lambda,R)].[\eta(\lambda,\lambda_L)G(R)]+N_B \quad (1)$$

$N_S(\lambda, R)$: Expected photon counts detected at wavelength λ and distance R; $N_L(\lambda_L)$: Number of transmitted photon; $[\beta(\lambda, \lambda_L, \theta, R)\Delta R]$: Probability that a transmitted photon is scattered by the scatters into a unit solid angle at angle θ; A/R^2: Probability that a scattered photon is collected by the receiving telescope; $[T(\lambda_L, R)T(\lambda, R)]$: Light transmission during light propagation from laser source to distance P and from distance R to receiver; $\eta(\lambda, \lambda_L)G(R)$: Overall system efficiency; N_B: Background and detector noise.

Lidar system simulation

The critical point in the Lidar system simulation program is the accurate estimation of Rayleigh scattering, density, and transmission through the atmosphere. Normally atmospheric densities can be obtained from the MSIS model (https://ccmc.gsfc.nasa.gov/modelweb/atmos/msis.html). MSIS atmospheric model density varies seasonally and locally. The number of photons emitted in a Lidar pulse can be estimated according to formula (2).

$$N_L(\lambda_L) = \frac{P_L(\lambda_L)\Delta t}{hc/\lambda_L} = \frac{E_{pulse}}{hc/\lambda_L} \qquad (2)$$

Depending on the reflectivity of the mirror and atmospheric transmission, the number of photons that reaches the location to be measured can be determined by formula (3).

$$N_{Tr} = N_L * R_{Tmirror} * T_{Atmos} \qquad (3)$$

Where: N_{Tr}: The number of laser photons that reaches R; $R_{Tmirror}$: Mirror reflectance coefficient; T_{Atmos}: Atmosphere transmission coefficient at wavelength λ.

The backscatter coefficient of the Rayleigh gas molecule $\beta(R)$ is determined from the available data on temperature and pressure obtained from the MSIS model by formula (4). Where λ is m, P is mbar, T is Kelvin.

$$\beta_m(\lambda, R, \theta = \pi) = 2.38 * 10^{-32} \frac{P}{T} * \frac{1}{\lambda^{4.0117}} \left(m^{-1} sr^{-1}\right) \qquad (4)$$

The number of elastic scattering photons by formula (5).

$$N_R = N_{Tr} * \frac{\beta_m(\lambda, R, \theta = \pi)}{n_{air}} \qquad (5)$$

n_{air}: Atmosphere density.

Estimation of the number of photons that reaches the surface of the principal mirror by formula (6).

$$N_{Primary} = N_R * T_{Atmos} * A \qquad (6)$$

The efficiency of the receiver system is related to the mirror image of the mirror, the transmittance of the standard optical instruments, the transmittance of the filter and the quantum efficiency of PMT (7) can be estimated as follows:

$$\eta_{receiver} = N_{primary} * T_{Rmirror} * T_{IF} * QE \qquad (7)$$

$R_{primary}$: Primary mirror reflectance coefficient; $T_{Rmirror}$: Receiver mirror transmission coefficient; T_{IF}: Filter transmission coefficient; QE: Quantum efficiency of PMT.

The number of photons obtained by PMT with the η receiver efficiency of the receiver system by formula (8).

$$N_P = \eta_{receiver} * N_{Primary} \qquad (8)$$

Algorithm scheme and diagram of the Lidar system simulation program were shown on fig. 3 and fig. 4, accordingly.

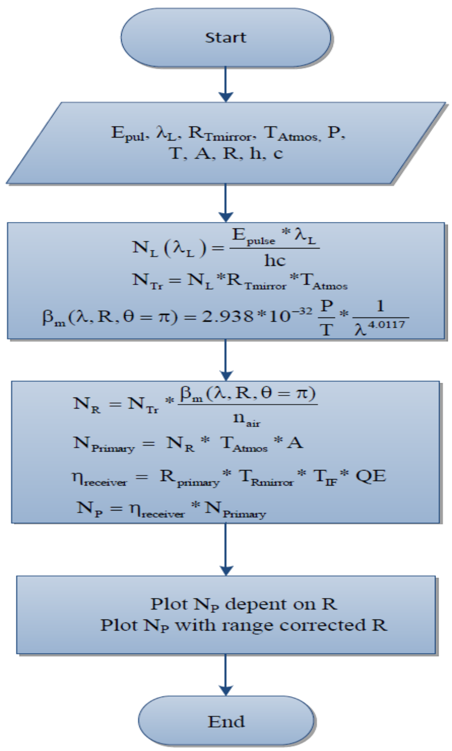

Fig. 3. Algorithm scheme

ABL, a lower part of atmospheric troposphere, directly affected by the impact of the Earth's surface, including friction drag, evaporation, heat transfer, pollutant emissions, and terrain influence, has an altitude of 300 to 3000m above the ground. One of the important ABL parameters is ABL altitude which can be determined by a variety of methods including meteorological column, soundings, the plane, sodar, cross wind, lidar, and the radio tomography using global positioning system (GPS). Each method has its own strengths and its limitations, so the best option is to use a combination of methods. Lidar method [16, 17] is based on the characteristics of signals backscattered from aerosol particles, so the aerosol lidar can be used to determine the temporal variability of the height of the convective layer in the ABL.

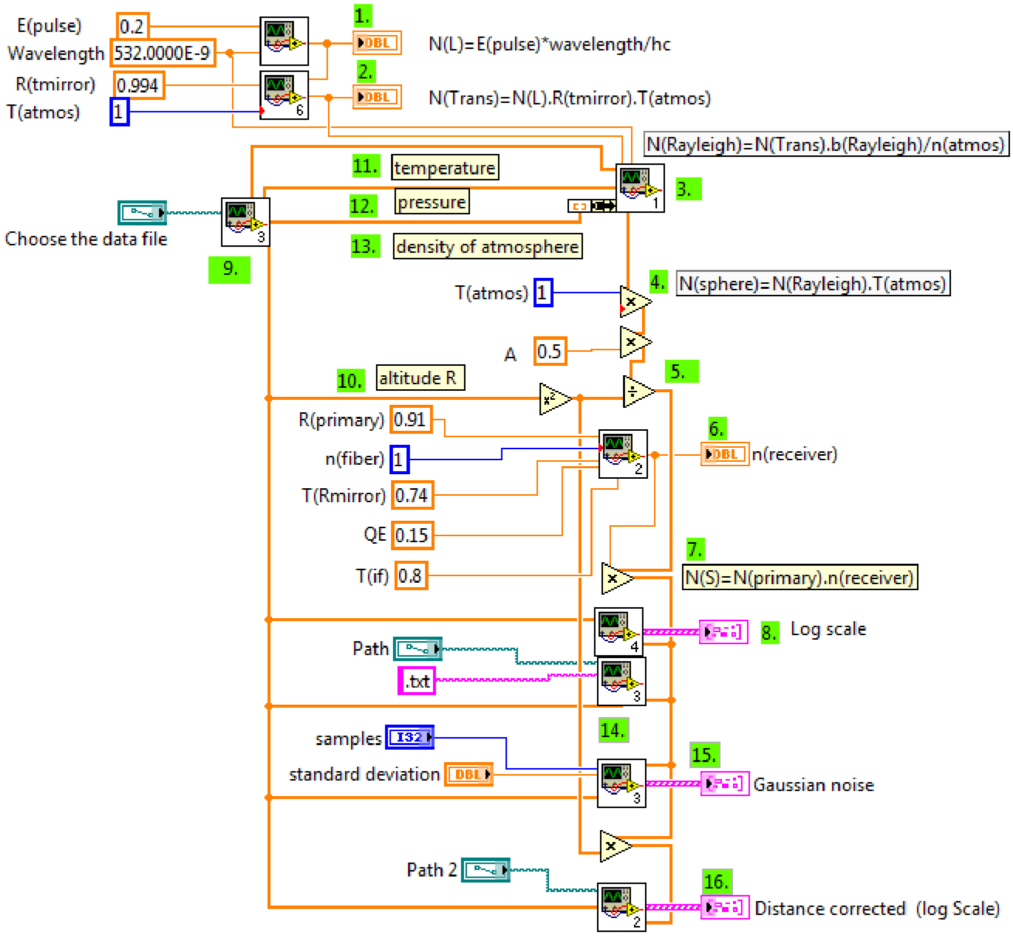

Fig. 4. Simulation block diagram

RESULT AND EXPERIMENTAL

Results of the lidar system simulation program (fig. 5).

The Lidar system (fig. 6) was studied, fabricated and finalized at the Institute of Geophysics for the purpose of studying atmospheric environments in general and aerosols, ABL in particular, based on input parameters of simulation software. The transmitter is a Nd-YaG laser system (LOTIS TII LS-2137U - Belarus) emitting at 1064 nm wavelength with a capacity of 700 mJ, 532 nm with a capacity of 400 mJ, 355 nm with a capacity of 160 mJ and 266 nm with a capacity of 120 mJ. The laser pulse emits directly into the atmosphere at 532 nm with a frequency of 10 Hz at 180 mJ. The Lidar signal from the atmosphere is collected by a 280 mm diameter Schmidt Cassegrain telescope, with aperture f/10. The optical signal coming from the optical glass goes to the convergent lens (2) and (3) converging with the beam of 40 mm cross-sectional response when out of the receiving antenna into a 10 mm parallel beam. A 532 nm interference filter with a narrowband bandwidth of 3 nm filters the background noise before the feedback signal passes through the polarized beam splitter (5) which separates the feedback signal at the 532 nm wavelength into components. Polarization is perpendicular and parallel to the polarization of the laser beam. These polarized optical signals is converted into electrical signals by the Hanamatsu PMT H6780-03 (6.7) having a working window ϕ = 8 mm operating at 532 nm. The photovoltaic electromagnetic signal is recorded by a high-speed oscilloscope (1 Ghz) connected to a computer via a USB port. Measured data is recorded in the file and processed by a dedicated software.

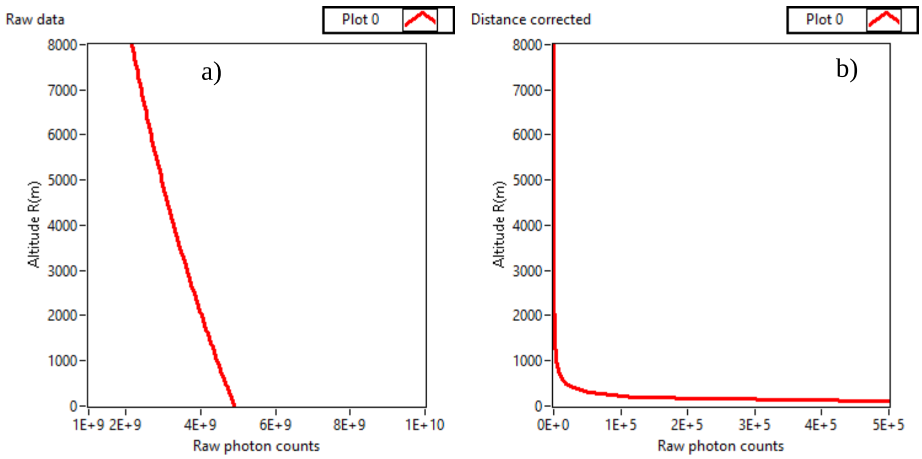

Fig. 5. Rayleigh signal received from simulation (a) depending with height, (b) distance corrected

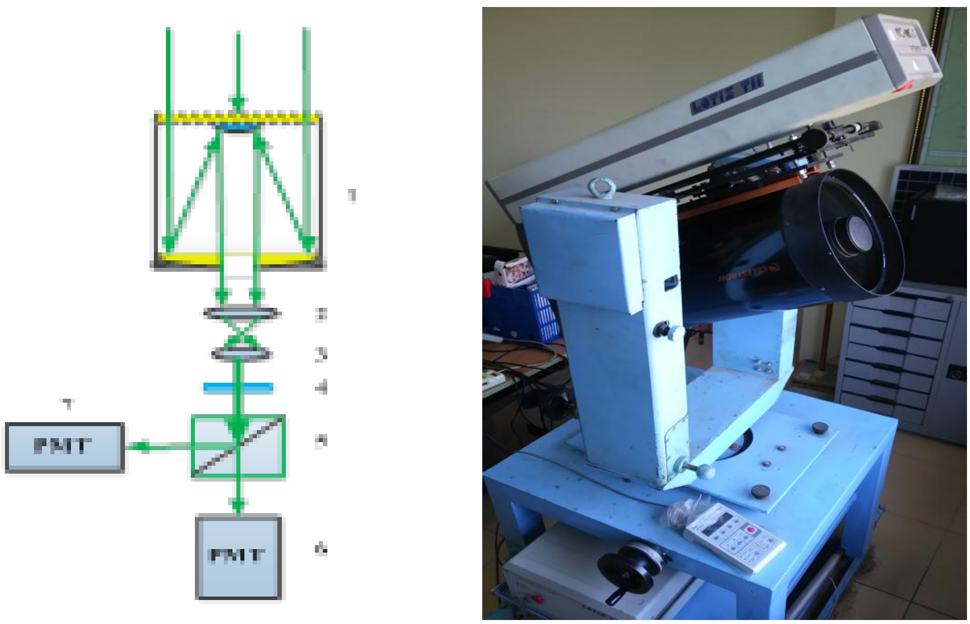

Fig. 6. The Lidar system at Institute of Geophysics

Fig. 7a is a plot of the simulation program running with the input parameters including: EL = 180 mJ, λ = 532 nm, ϕ = 8 mm, τ = 8 ns, f = 10 Hz; Amplification coefficient of PMT (approximately 10^4). Fig. 7b shows the case study at 9.30 on 26/10/2016: Reception signal generated by the real Lidar system (at Institute of Geophysics - 18 Hoang Quoc Viet, Cau Giay, Hanoi) with the same parameters with the elevation of the system of 25 degree.

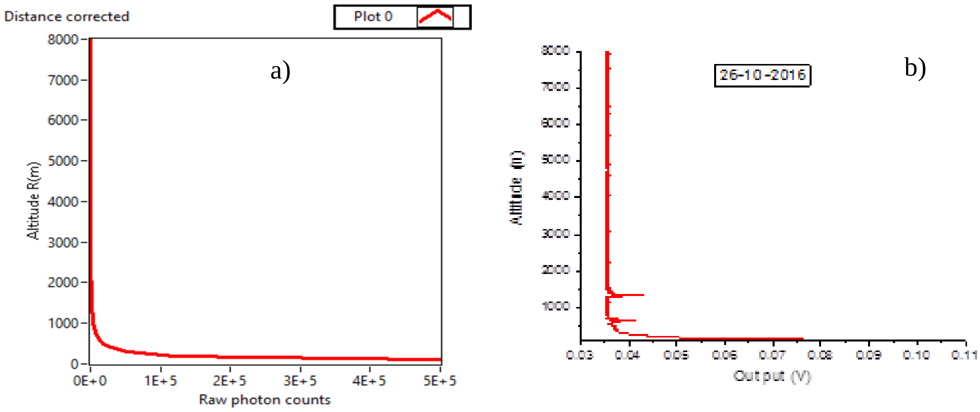

Fig. 7. (a) Simulation signal, (b) Measured signal at λ =532 nm

Signals from the Lidar system showed two surges at altitudes of 560 m and 1345 m. This is an evidence of the reflection signal of the two cloud layers that the laser beam encounters and reflects back. According to sounding data on 26/10/2016 at 7 am at Lang station - Hanoi, the area had a cloud at height of about 1053 m. With these two initial comparisons, the Lidar signal obtained from the real system is reliable and consistent with the simulation signal.

CONCLUSION

We have succeeded in designing and improving the lidar system for studying atmospheric environments in general and aerosol monitoring and ABL study in particular. Initial results showed that the Lidar system was designed with the good sensitivity and precision.

Designing the lidar system is a complex task requiring in-depth understanding of electronics, informatics, optics, atmospheric physics, and precision engineering. The lidar system is modularly designed and can be flexibly modified and developed for new modules for different purposes of research and application. The design and improvement of the lidar system should be based on object-oriented simulation software to clarify the advantages and disadvantages of each specification of each structural module, thus offering optimal technical solutions.

With the above system and simulation software, in the future we will proceed the following investigations: lidar signal measurements with predetermined target to evaluate the measurement errors; comparison between the signals obtained by real system with the MSIS model at several heights; calculation of ABL height and evaluation of system and background noises at different time scales such as seasons of the year and during the day.

Acknowledgements: The research funded from Project “Study on atmospheric boundary layer using lidar technology in the Asia - Pacific ocean-continent transition sector” (VAST.HTQT. Nga.13/12-13) was acknowledged.

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