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Original research article

Construction of backscattering echo caused by cloud in laser fuze

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ABSTRACT

Laser fuze is a weapon subsystem that uses laser to detect, identify and detonate in due time the target in short distance (generally not more than 10 m), and its working performance can be easily affected by the backscattering echo caused by cloud and other atmospheric particles. In this paper, we took the laser fuze and cloud of low visibility (less than 100 m) as the research subject, and established the laser detection model in cloud based on the Mie theory and Monte Carlo method. Using the laser detection model, we simulated the generation of cloud backscattering echo for the laser with 860 nm, and obtained the number of scattering events, penetration space and transmission time inside cloud of the echo, and analyzed the construction of echo on these aspects and the influence of cloud particle size parameter on the construction of echo. The data and results obtained in this paper can provide important support for the characterization of cloud backscattering laser echo, and the design of methods of laser anti-interference in cloud.

1. Introduction

Fuze, an important part of weapon system, has the function of detecting, identifying and detonating in due time the target in short distance [1,2]. Laser fuze, which uses laser to detect and identify targets, has the advantages of strong anti-electromagnetic interference and high accuracy in positioning [3]. However, laser fuze can be easily affected by atmospheric particles. When laser fuze encounters the cloud of low visibility in air, the cloud will produce a strong backscattering echo of laser fuze, forming a false echo that would lead to the false alarm and premature explosion of the laser fuze.

It is an effective way to improve the performance of the laser fuze in the cloud of low visibility by identifying the target echo and the backscattering echo caused by cloud through the beam characteristics. But it is necessary to conduct an in-depth analysis on the characteristics of the backscattering laser echo. D. M. Winker and D. Kim studied the proportion of multiple scattering echoes in the backscattering echo of cloud [4,5]. V. V. Belov studied the spatiotemporal structure of the backscattering echo of cloud [6], and R. Krawczyk studied the pulse broadening of cloud backscattering echo [7]. However, all of the above studies are conducted on the detection of laser radar within the range from several kilometers to several hundred kilometers, and the cloud with visibility greater than 100 m. Thus, the data and conclusions obtained may not be applicable to laser fuze whose detection range is short (generally not more than 10 m) and clouds of lower visibility. W. Zhang and H. M. Chen respectively studied the cloud echo characteristics of FMCW laser fuze and pulse laser fuze [8,9], but their studies only focused on the waveform of cloud echo. Therefore, based on the laser detection model set up by the method of Monte Carlo, this paper further studies the characteristics of cloud backscattering laser echo, including the number of scattering events, the penetration space and transmission time of echo with laser fuze and the cloud of low visibility (less than 100 m) as the research objects.

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2. Laser detection model

A more perfect laser detection model in cloud is built by adding the optical shaping process on the basis of previous work [10]. According to the detection process of laser detection system in cloud, the laser detection model can be divided into two sub-models: the laser transceiver model and the laser transmission model.

(1) Laser transceiver model

The laser transceiver model is used to simulate the laser emission, optical shaping and receiving processes of laser detection system. The model disperses a beam of light into a large number of photons, and emits them sequentially in chronological order according to the emission time, position and direction of photons. The spatial positions of photons at the emission moment follow Gauss distribution, which can be expressed as:

$$\begin{cases} x = \omega_0 \xi_1 \\ y = \omega_0 \xi_2 \\ z = 0 \end{cases} \tag{1}$$

where ω_0 is the radius of laser beam waist, ξ_1, ξ_2 are the random numbers of standard normal distribution. The direction of photons at the emission moment can be obtained by the following equations:

$$\begin{cases} u_x = \sin\theta_0 \cos\varphi_0 \\ u_y = \sin\theta_0 \sin\varphi_0 \\ u_z = \cos\theta_0 \end{cases} \tag{2}$$

where $\theta_0 = |(\theta'/2)\cdot\xi_3|$ is the zenith angle of photon emission direction, θ' is the divergence angle of laser beam, ξ_3 is the standard normal distribution random number, $\varphi_0 = 2\pi\cdot\xi_4$ is the azimuth angle of photon emission direction, ξ_4 is the uniform random number in the interval [0,1].

The model will adjust the transmission path via the emission optical shaping system before emitted photons transmission in external environment. When photons pass through the emission optical shaping system, the refraction direction of photons at the optical lens incident end, the photon move trajectory inside the optical lens, and the refraction direction of photons at the optical lens exit end are calculated sequentially according to the structure size and refractive index of optical lens and the incident position and direction of photons at the optical lens incident end to obtain the position and direction of photons after passing through the optical shaping system.

For the returned photons due to cloud particles backscattering, the laser transceiver model, in turn, determines whether they can enter the receiving optical shaping system; and whether they can enter the photodetector after the receiving optical shaping. The receiving optical shaping process is similar to the emission optical shaping process. If both conditions satisfy the requirements, the photons will be received successfully and generate the cloud backscattering echo. For the photons received by laser detection system, the laser transceiver model can obtain the information such as the number of scattering events, the propagation trajectory, and the transmission time. The number of scattering events can be obtained by counting the number of collision between photons and cloud particles. The transmission time can be obtained by the following equation:

$$t = L/c \tag{3}$$

where L is the move distance of photons during the detection process, and c is the light speed.

(2) Laser transmission model

The laser transmission model is used to simulate the transmission process of photons in cloud, which includes the collision between photons and cloud particles, and the move process of photons in cloud.

The collision between photons and cloud particles will lead to the scattering and absorption of photons, thereby changing the photon propagation direction and energy. The photon propagation direction after collision is determined by the following expression [11]:

$$\begin{cases} u'_x = \sin\theta(u_x u_z cos\varphi - u_y sin\varphi)/\sqrt{1-u_z^2} + u_x\cos\theta \\ u'_y = \sin\theta(u_y u_z cos\varphi + u_x sin\varphi)/\sqrt{1-u_z^2} + u_y\cos\theta \\ u'_z = -\sin\theta\cos\varphi\sqrt{1-u_z^2} + u_z\cos\theta \end{cases} \tag{4}$$

if $|u_z| > 0.99999$, the Eq. (4) is changed to:

$$\begin{cases} u'_x = \sin\theta\cos\varphi \\ u'_y = \sin\theta\sin\varphi \\ u'_z = u_z/|u_z|\cdot\cos\theta \end{cases} \tag{5}$$

where u_x, u_y, u_z are the propagation direction before collision, φ is the azimuth angle and uniform distributed between 0 and 2π, θ is the scattering angle, and can be obtained by sampling based on the weights of scattering angles 0° - 180°, which are expressed by the scattering phase function as follows [8]: