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Original research article

Influence of rough surface on the ranging distribution of constant fraction discriminator

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ABSTRACT

Aiming effect of the rough surface on the pulse laser ranging distribution of Constant fraction discriminator (CFD), based on the traditional laser radar equation and rough surface characteristic, incoherent pulse laser detection equation of plane target is derived considering launch process as the shock response of linear system. Based on principle of CFD, the probability density function of ranging distribution of CFD is derived. The pulse laser CFD distribution with rough plane is deduced with the echo equation and probability density function. The influence of different plane angles, reflectivity, noise characteristics and pulse width on the distance distribution is analyzed by simulation. The simulation results show that CFD can effectively suppress walk error caused by different angles of rough plane.

1. Introduction

Pulse laser ranging has the advantages of high repetition rate, high measurement speed, high precision, long distance and strong anti-interference ability [1]. Therefore, the pulse laser ranging has been widely used in military and civil fields [2–5]. In laser ranging system, time discrimination methods including Leading edge discriminator (LED), Constant fraction discriminator (CFD) and Peak detection (PD) is critical [6]. LED produces large walk error of a few of nanosecond. PD effectively reduces walk error. However, PD is limited to range. CFD is not affected by the amplitude of echo signal. Therefore, CFD is extremely appropriate to large dynamic ranging.

Aiming at the distribution of laser ranging, Johnson and Cain studied the range accuracy of laser radar system. They derived CRLB of ranging accuracy considering Poisson noise distribution [7,8]. Jiang derived the theoretical ranging distribution with the method of LED and PD [9,10]. Experiments are carried out to verify the theory. However, Jiang ignores target surface characteristics on the influence of the range distribution. Therefore, ranging distribution characteristics have certain limitations. The influence of different target shape parameters on the laser radar cross section and ranging precision was analyzed by Steinvall and Gronwall [11–13]. Receiver signal model is established by KOU [14]. The probability density function (PDF) of receiver signal accords with Rice distribution with different Signal-to-noise (SNR). But he neglects characteristics of the plane. WANG [15] studies the factors affecting the accuracy of the target range by using numerical simulation. CAO proposed a dual channel differential optical path ranging method to reduce the influence of background noise on the accuracy of the measurement [16–18]. XU discussed the boundary condition of the range variance of laser circular-viewing system, and deduced CRLB of different tilt plane [19]. They have not obtained the PDF of range with CFD method and rough plane target characteristic.

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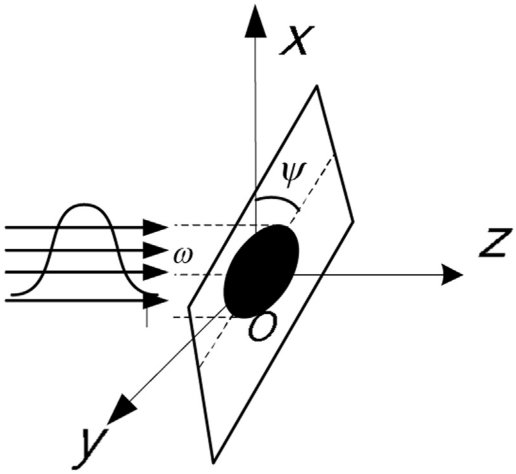

Fig. 1. Detection model of rough target.

In this paper, based on traditional laser radar equation and rough plane characteristic, incoherent pulse laser receiver signal model is deduced considering launch process as the shock response of linear system in Section 2. In Section 3, the PDF of CFD is derived based on the principle of traditional CFD. In Section 4, the effects of different tilt angle, reflectivity, noise and pulse width on PDF of CFD are analyzed by simulation.

2. Received laser signal model

In pulse laser ranging system, the transmitter and receiver could be considered as coaxial system. The coordinate of the laser detection system is illustrated in Fig. 1. The laser beam is parallel to axis z. The center of rough plane is at point O. ψ is the title angle of rough plane.

Received laser signal model is [20]:

$$P_r = \frac{P_t G_t}{4\pi R_t^2} \frac{\sigma}{4\pi R_r^2} \frac{\pi D^2}{4} \eta_{\text{atm}} \eta_{\text{sys}} \tag{1}$$

where P_t is transmitted peak power, G_t is antenna gain, R_t is range between laser transmitter and target, R_r is range between laser receiver and target, σ is radar cross section, D is the diameter of receiver optical system, η_{atm} is atmospheric transmittance, and η_{sys} is optical transmittance.

It is assumed that the spatial distribution of laser beam obeys Gaussian distribution. The laser irradiance distribution is [12]

$$E(x,y,z) = \frac{2P_t}{\pi\omega^2(z)} \exp\left(-2\left(\frac{x^2+y^2}{\omega^2(z)}\right)\right), \tag{2}$$

where $\omega(z)$ is the beam radius. It is:

$$\omega(z) = \omega_0\sqrt{1+(\lambda z/\pi\omega_0^2)^2} \tag{3}$$

where ω_0 is waist radius at the 1/e point at the laser source, and λ is pulse laser wavelength. $\omega_0 = 2\lambda/\pi\varphi$, φ is the beam divergence angle.

A Gaussian function is used as the laser time distribution model:

$$P_t(t) = P_0 \exp\left(-t^2/\tau^2\right), \tag{4}$$

where P_0 is the peak time for the laser pulse, and τ is laser output pulse width.

The single station radar cross section equation of unit surface element is [11]:

$$d\sigma = 4\pi f_r(\beta)\cos^2\beta dA, \tag{5}$$

where $f_r(\beta)$ is bidirectional reflectance distribution function (BRDF), dA is area of unit scattering element, and β is incident angle.