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Research on Detection Performance in Laser Ranging System

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Abstract. To the laser ranging system which has the issues of low detection sensitivity and poor ranging accuracy in the field surroundings, the photoelectric detection technology based on avalanche photodiode APD was proposed to research the photoelectric detection performance. According to the working principle of laser ranging, optical emission institutions and detection institutions of the laser ranging system were analyzed, and the working performance of APD was analyzed; combining the practical request of ranging, the geometric optical paths of ranging system was designed and analyzed; in terms of the atmospheric attenuation and emitting laser power and other aspects, the field surroundings of optical detection performance was researched. By the calculation and analysis, under the specific known conditions, the relationship between the emitting laser wavelengths and atmospheric attenuation, relationship between the detection distances of detection system and receiving laser power of detector were given.

Keywords: laser ranging system; APD detector; atmospheric attenuation; detection distances

1. Introduction

Laser radar is the active laser detection equipment, it can be used for terminal guidance, the terminal sensitivity of smart munitions and other sensitive areas of target detection, and it is a new laser guidance system [1]. Laser technology and echo detection technology have gained great progress in the manufacture of weapons, and have been used in weapons design. Currently, the laser radar detection technology is gaining a rapid development. The laser radar detection system has mainly completed the information acquisition for laser detection technology at home and abroad [3]. However, these laser radar technologies have the main problems which are low measuring sensitivity and poor anti-interference ability and low accuracy in complex working surrounding. For these issues, the photoelectric detection technology based on avalanche photodiode APD was proposed to research the detection performance in this paper. In terms of the atmospheric attenuation and emitting laser power and other aspects, the complex surroundings of optical detection performance was studied. By the calculation and analysis, under the specific known conditions, the relationship between the emitting laser wavelengths and detection distances of detection system and signal intensity of detection receiver was given.

2. The Principle of Laser Ranging

2.1. Laser Ranging System

The block diagram of laser ranging system is shown in Fig.1, the drive pulse of laser transmitter based on a certain wavelength has a certain power; this laser scans the surface by optical emission institutions; the optical detection institutions detect echo signal which was reflected by the target; the echo signal was filtered by the optical filter, and the echo signal was amplified, filtered, shaped, etc., by the weak echo signal receiving institutions progress; at last, we can get the target distance information by the echo signal progressing.

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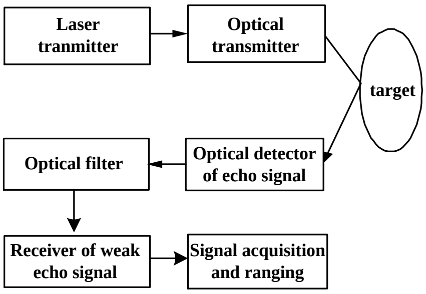

Figure 1. Block diagram of the laser ranging system

2.2. Optical Schematic of Laser Ranging System

The working block diagram of laser ranging system is shown in Fig.2. The laser beam, which was outputted by laser, has high repetition rate and narrow pulse. The laser beam was reflected and coupled by the mirror M1, M2, then the laser beam coincides with the optical axis of receiving optical telescope, which can achieve the optical coupling and isolation of the transmitting and receiving. And then the laser beam forms scanning field in a range of two-dimensional scanner by two-dimensional scanner. Part of the laser into the detector by the lens, they form the dominant wave signal. The laser beam was reflected by the target, the reflecting laser signal was reflected in the optical telescope by the same two-dimensional scanner, and then the laser signal was gathered in the APD detector, forming echo signal. The dominant wave signal and echo signal were amplified, filtered and shaped by the receiver, then the receiver outputted a certain range of voltage signal, and sent the voltage signal to the part of calculation of the signal acquisition, which can compute pulse, and measure the time delay which was between the echo signal and the dominant wave signal, and calculate the distance of each detecting matrix.

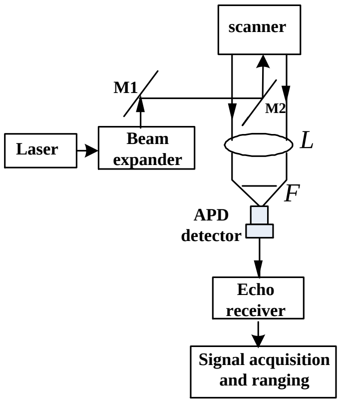

Figure 2. Optical schematic of laser ranging system

2.3. The Detection Sensor and Processing of Echo Signal

1) The selection of detection sensor

In order to obtain the reflected signals of output laser, the model selection of photodetector plays a very important role in ranging system. General photoelectric detectors, which have low sensitivity and large noise, will seriously affect the optical characteristics of the laser echo signal [4]. If the performance of photoelectric device selected is poor, echo signal will be submerged in the background noise. Therefore, what the choice of the appropriate photoelectric device for the whole detection system is the top priority. Previous photoelectric device is PIN photoelectric diodes, which have weak anti-interference ability, therefore, this paper puts forward the APD photoelectric detectors which have high response and low noise as sensor, thanks to this device has the advantages which are high sensitivity, high response, strong anti-jamming capability etc., such detector can improve detection Performance.

2) The processing of echo signal of detection sensor

According to Fig.2, we will research the processing of echo signal as follow .The block diagram of working principle of receiver is shown in Fig.3. Avalanche photodiode (APD) has completed the conversion which was optical signal to electrical signal, and the electrical signal was formed after a certain range of voltage signal by the preamplifier, then the voltage signal was shaped and computed ranging in the circuit of signal acquisition. Automatic gain control circuit (AGC) can automatically control the avalanche gain of APD under the size of output signal of the preamplifier so as to make APD work in the best condition.

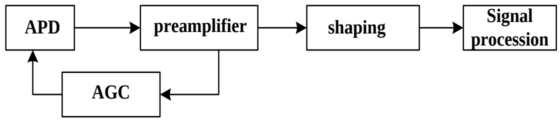

Figure 3. The block diagram of working principle of receiver

3. Performance Analysis of Detection System In Complex Ground Environment

Although the detecting capability of laser ranging system closely relates with the choice of photoelectric sensors, the detecting capability closely relates with the atmospheric transmission and the reflecting character of target.

3.1. Atmospheric Attenuation

Laser attenuation can affect the detection performance of the system in the atmosphere; we need to homologous study this factor. Laser was transmitted in the atmosphere, the effect from atmospheric interference is main as a result of distribution non-uniform of the atmospheric density, which results in laser along the light path generated refraction, and the laser was absorbed and scattered by the atmospheric gas molecules and aerosol particles, dust, fog, rain and so on, which may cause the laser signal attenuation [5]. Atmospheric turbulence caused the variable energy distribution on the beam cross section and the expansion and drift of the beam, due to the change of air density was caused by atmospheric absorption and the change of refractive index results in the beam phase shift, etc [7].

In the lower atmosphere [2], the relationship between atmospheric attenuation coefficient $\sigma(\lambda)$, laser wavelength λ and horizontal visibility R_v can be shown in the empirical (1).

$$\sigma(\lambda) = \frac{3.91}{R_v}\left(\frac{550}{\lambda}\right)^q \tag{1}$$

Where, R_v is visibility, which is corresponding visible distance between the laser of wavelength $\lambda = 550nm$ and transmissivity of medium is 2%, q is modifying factor, which is shown in (2).

$$\begin{cases} q = 1.6 & R_v > 50km, \\ \mathrm{q} = 1.3 & R_v \approx 10km, \\ \mathrm{q} = 0.585 R_v^{\frac{1}{3}} & R_v < 6km, \end{cases} \tag{2}$$

In this paper, the responsivity of APD detector relates with wavelength in the laser radar ranging system. By data-book of APD, we know that the responsivity is maximum, when wavelength λ is about $905nm$. So we need to consider the relationship between attenuation coefficients and wavelength in the condition of medium visibility ($R_v \approx 10km$).

In the eq. (2), with wavelength increasing, the atmospheric attenuation is increasing, we combine the relationship between responsivity of APD and wavelength, and so in this paper wavelength λ is $900nm$.

From the above analysis shows that atmospheric attenuation, the capability of the laser ranging is affected by the atmospheric attenuation coefficient. We can use the method of empirical formula of atmospheric attenuation, thus we can ensure the accuracy of the laser ranging.

3.2. The Emitting Laser Power

Usually, the more emitting laser power, the stronger penetration, and the attenuation are smaller. According to the principle of laser ranging system, the accuracy of laser ranging system relates with the emitting laser power.

The emitting laser power which fulfils the requirements of the laser ranging system, it relates with a number of factors, it can be obtained by the following eq. (3):

$$P_t = \frac{2\pi R P_s}{\tau_t e^{-2\sigma(\lambda)R} \rho_t \cos\theta \tau_r A_r} \tag{3}$$

Where, P_t is emitting laser power, P_s is irradiation power of the laser beam, τ_t is the transmissivity of the emission system, τ_r is the transmissivity of the receiving system, $\sigma(\lambda)$ is the atmospheric attenuation coefficient, R is distance between detector and target, ρ_t is reflectivity of target, θ is angle which is normal and incidence angle, A_r is area of the receiving aperture.

In eq.(3), when the sensitivity of the system was confirmed, we can increase the distance R, by increasing emitting laser power, decreasing the loss of receiving optical system, and increasing receiving aperture. In fact, when the laser ranging system was designed, the detector just relates with the reflective character of target for the operating distance of the different target.

3.3. The Reflective Character of Target

The receiving laser power of detector relates with emitting laser power, at the same time, the receiving laser power of detector relates with the reflective character of target. When the sequence of the pulse laser was emitted by a certain repetition frequency repetition frequency, the surface of target for the reflective character of the laser will directly affect detecting capability of the target. Therefore, research and analysis of effective reflection character of the target is an important part of the study on photoelectric detection.

We assume that the laser is transmitted in the atmosphere, in compliance with the law of geometrical optics, namely, the same direction and uniform. Energy distribution within the laser beam is approximately uniform or axisymmetric; the reflection of the incident light is diffuse reflection. Therefore, the reflecting character can measure by the diffuse reflectance, namely the ratio of reflected power and incident power [6]. When the laser was reflected to the receiver, in the APD detector, echo power P_r can be gained by (4):

$$P_r = \frac{2 P_t \tau_t \tau_r A_s A_r \rho \cos\theta}{\pi R^4 \theta_t^2} e^{-2\sigma(\lambda)R} \tag{4}$$

Where τ_t is transmittance of optical emission institutions, τ_r is transmittance of receiving institution, θ_t is divergence angle of laser beam, $\sigma(\lambda)$ is the atmospheric attenuation coefficient, R is distance of the target and the laser firing point, A_s is Target area, A_r is effective collecting area of receiving system, θ is angle which is normal and incidence angle, P_r is the receiving laser power of detector, P_t is emitting laser power, ρ is the target of the diffuse reflectance.

When the target size is larger than the spot size, and then $A_s \cos\theta = \pi (R\theta_t)^2 / 4$. In fact, the surface reflective character of target is not uniform; the intensity of the reflected light is the strongest in the incident direction, with the increasing angle of incident light, the intensity of reflected light gradually decreases. When the angle is 90°, reflected light intensity approximate is 0. The specific distribution of reflected light was determined by the surface reflective character of target. However, starting from qualitative aspects, we can use cosine distribution instead of uniform distribution, namely the surface reflective intensity of target is double of the uniform distribution in the incident direction, so in the photosensitive surface of detector, the reflected light power P_r can be wrote as (5):

$$P_r = \frac{P_t \tau_t \tau_r A_r \rho}{\pi R^2} e^{-2\sigma(\lambda)R} \tag{5}$$

When the distance of the laser emission system and the target system is closer, we can not consider the impact of atmospheric attenuation in the atmosphere when the laser beams were transmitted. So when the laser beams pass the surface of detector the reflection light power P_r can be gained as (6):

$$P_r = \frac{P_t A_r \rho}{\pi R^2} \cos\theta \tag{6}$$

Where, θ is incidence angle which is in between the normal of the surface of target and the optical axis of optical receiver.

Because the impact of environment for the reflection character of the target, we know the detector and the target have a certain distance, when the distance is different, the measured reflection intensity target is different.

4. Calculation andAnalysis

By the third section, we know that receiving laser power of the detector was affected by the atmospheric attenuation, and emitting laser power determines the detection distance. We combine those factors, and get the Fig. 4 by the eq. (1) ~ (5). In the Fig.4, when $\tau_t = \tau_r = 0.98$, $\rho = 0.1$, $P_t = 5w$, $A_r = 10cm^2$, $\sigma(\lambda) = 2.05 \times 10^{-4}$, the relationship between the detection distance and receiving laser power. From the Fig.4, when the far detection distance, the receiving laser power of detector is obvious decreasing, so we can see the influence of atmospheric attenuation is very large, the atmospheric attenuation can not be ignored.

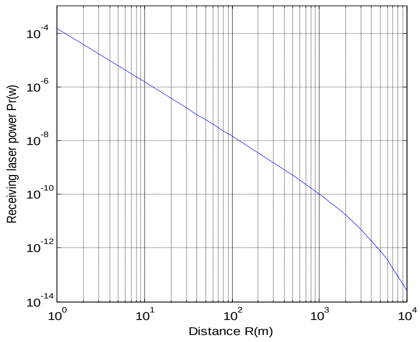

Figure 4. The relationship between detection distance and receiving laser power

When the distance of the laser emission system and the target system is closer, we can not consider the impact of atmospheric attenuation in the atmosphere when the laser was transmitted. In the Fig.5, if $\rho = 0.1$, $P_t = 5w$, $A_r = 10cm^2$, $\theta = 0^\circ$, the atmospheric attenuation can be ignore, so we can see the relationship between detection distance and receiving laser power.

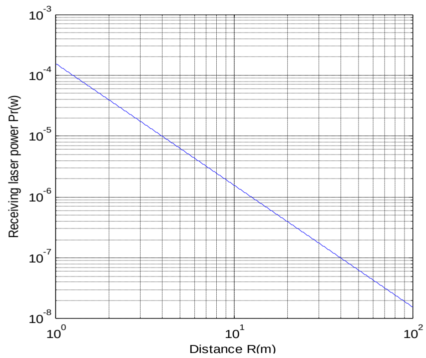

Figure 5. The relationship between detection distance and receiving laser power without atmospheric attenuation

5. Conclusion

Based on the principle of laser ranging, the optical character, the characteristics of APD sensor, the reflection characteristics of target and the influence of photoelectric detection system with atmospheric attenuation were researched and analyzed. By the calculation, we can see that detection performance of the system was restricted by the factors, which are emitting laser power, atmospheric attenuation, and distance. If we want to improve the detection performance, we need to increase the emitting laser power or to improve amplifier of the receiving system, and to select photoelectric receiving device which has higher responsiveness. In this paper, studying can provide theoretical basis to the subsequent designing and improvement of laser ranging system.

6. Acknowledgment

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