Factors affecting laser power received in system of tracking, acquisition and pointing in space

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Estimating formula of the smallest power of illuminating laser of tracking, acquisition and pointing system in space is founded, and the smallest value that the illuminating laser sends when the receiving system can detect the return signal is obtained. The radiant intensity and the radiant quantity reflected by the diffuse reflection target of secondary planet are researched in theory and simulation. It is concluded that the distributing area of radiant emittance and the radiant intensity are the same as the figure of surface of projection in section of laser beam. The factor which affects radiant quantity of secondary planet is the effective area of projection, which includes the reflecting area of secondary planet and the angle between surface of projection and reflecting surface. The factors which affect the radiant intensity are the area of projection in section of laser beam and the angle between the direction of laser beam and normal of reflecting surface. The radiant intensity and quantity of secondary planet affect laser power of receiving system directly.

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Because of the special trait of space in geographical position, it is important for the polity, economy, army, and diplomatism. After forty years' developing in space, the new coming industries of communication, remote sensing and navigation have been built. The industry of biology project and material processing will be built in the future. In order to control the space resource, the research of confronting weapon in space is the most important one, including the increasing of defending and attacking ability in space. The tracking, acquisition and pointing technologies[1−5] are the base of laser communication in space. In this paper, the smallest value that illuminating laser sends when the receiving system can detect the return signal and the distributing characteristic of radiant intensity and quantity that diffuse reflection target of secondary planet reflects are obtained. These researches are important for using resource of aircraft and studying the tracking, acquisition and pointing technology and rivalry in optical and electronic system. They will offer the parameter of veracity and stability for the tracking, acquisition and pointing system, save resource, and increase efficiency.

In this paper, the used wavelength of laser beam of tracking system was 1064 nm. The beam lighted the small secondary planet that was long from laser machine. The telescope was set at the export of laser beam, the distance between laser and secondary planet and position of secondary planet were measured by receiving laser signal reflected by the secondary planet. As shown in Fig. 1, the lighting and scanning system includes the sending equipment of laser lamp-house, the secondary planet in cube shape, and the receiving telescope. In the experiment, laser beam scanned and pointed the secondary planet in a frequency and scanning angle. After aiming at secondary planet, the reflected laser signal was received by receiving telescope. The quadrant avalanche photodiode (QAPD) which was set behind telescope could measure the position of secondary planet. The power which QAPD could detect was bigger than a numerical value, so power which laser sends had a small numerical value.

The lidar formula is used for computing the smallest value that illuminating laser sends when receiving system can detect the return signal[6],

$$\frac{P_{\mathrm{R}}}{P_{\mathrm{T}}}=\frac{A_{\mathrm{T}}}{\frac{\pi}{4}\pi\left(\theta_0 L\right)^2}\frac{\frac{A_{\mathrm{R}}}{L^2}}{2\pi}K_{\mathrm{f}}K_{\mathrm{R}}K_{\mathrm{T}}\rho, \tag{1}$$

where P_{T} is laser power of sending, P_{R} is received power of detecting machine, L is distance between laser machine and secondary planet, K_{f} is permeation rate of filter in peak value, $K_{\mathrm{R}}K_{\mathrm{T}}$ is permeation rate of sending and receiving optical system, ρ is reflecting rate of radiated target, θ_0 is divergence angle of laser beam, $A_{\mathrm{R}}=\frac{\pi}{4}D^2$ is receiving area of receiving telescope, D is diameter of receiving telescope, A_{T} is effective reflecting area of target secondary planet. According to the experiential value and in order to compute easily, it is assumed that $\theta_0=0.6$ mrad, $K_{\mathrm{R}}K_{\mathrm{T}}=0.3$, $K_{\mathrm{f}}=0.9$, $\rho=0.1$, $L=10000$ m, $P_{\mathrm{R}}=2\times10^{-8}$ W, $D=0.1$ m.

The secondary planet is of the cube shape, it is assumed that the center of beam is the same as the vertex of the cube. The sides of cube are $a=b=c=0.5$ m, angles between the sides and the section of laser beam at 10000-m distance are α, β, and γ, as shown in Fig. 2. The area of projection against laser beam in the section is A_{T}, so the effective reflecting area is

$$\begin{aligned}A_T=\;&ab\sqrt{1-(\sin\alpha)^2-(\sin\beta)^2}\\&+ac\sqrt{1-(\sin\alpha)^2-(\sin\gamma)^2}\\&+bc\sqrt{1-(\sin\beta)^2-(\sin\gamma)^2},\end{aligned} \tag{2}$$

with $(\sin\alpha)^2+(\sin\beta)^2+(\sin\gamma)^2=1$.

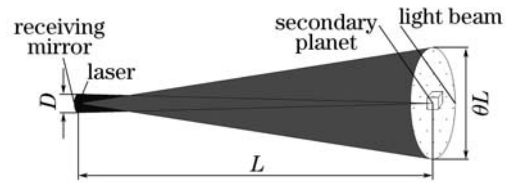

Fig. 1. Schematic of the lighting, tracking and receiving system.

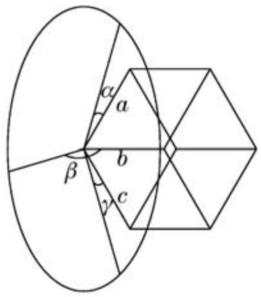

Fig. 2. Relative position of the cube under the irradiation of laser beam.

The changes of area of projection can be obtained from MATLAB computing. The change of area of projection becomes bigger and then smaller with the increase of α, β, as shown in Fig. 3. At $\alpha = 0$, $\beta = 0$, $\gamma = 1.57$ rad, the area of projection is the smallest one, about 0.25 m^2; at $\alpha = 0.644$ rad, $\beta = 0.644$ rad, $\gamma = 0.644$ rad, the area of projection is the biggest one, about 0.433 m^2.

The formula of the smallest value of sending laser power is

$$P_{\mathrm{T}} = P_{\mathrm{R}} \frac{\frac{\pi}{4}\pi\left(\theta_0 L\right)^2}{A_{\mathrm{T}}} \frac{2\pi}{\frac{A_{\mathrm{R}}}{L^2} K_{\mathrm{f}} K_{\mathrm{R}} K_{\mathrm{T}} \rho}. \tag{3}$$

When the area of projection is the smallest one, the smallest value of sending laser power is 6.6987×10^6 W. When the area of projection is the biggest one, the smallest value of sending laser power is 3.8498×10^6 W. So the smallest value is $P_{\mathrm{T}} = 6.6987 \times 10^6$ W.

Without considering permeation rate of filter in peak value, permeation rate of sending and receiving optical system, laser power received by the telescope is

$$P_{\mathrm{R}} = \frac{P_{\mathrm{T}}}{\frac{\pi}{4}\pi\left(\theta_0 L\right)^2} \frac{\frac{A_{\mathrm{R}}}{L^2}}{2\pi} \rho A_{\mathrm{T}}. \tag{4}$$

Assumed that radiant intensity of laser beam is I, the power arriving at the surface of secondary planet can be obtained from

$$\begin{aligned} P_{\mathrm{R1}} &= \frac{P_{\mathrm{T}}}{\frac{\pi}{4}\pi\left(\theta_0 L\right)^2} A_{\mathrm{T}} = \frac{I}{L^2} A_{\mathrm{T}} \\ &= \frac{P_{\mathrm{T}}}{\frac{\pi}{4}\pi\left(\theta_0 L\right)^2} A\cos\theta = \frac{I}{L^2} A\cos\theta. \end{aligned} \tag{5}$$

The radiant intensity of laser beam is

$$I = \frac{P_{\mathrm{T}}}{\frac{\pi}{4}\pi\left(\theta_0 L\right)^2} L^2. \tag{6}$$

In Eq. (5), θ is the angle between reflecting surface and section, A is the total area of reflecting area.

The radiant quantity of secondary planet reflecting is

$$P_{\mathrm{T}}^1 = \frac{P_{\mathrm{T}}}{\frac{\pi}{4}\pi\left(\theta_0 L\right)^2} A\rho\cos\theta = \frac{I}{L^2} A\rho\cos\theta. \tag{7}$$

It is obtained from Eq. (7) that the radiant emittance of diffuse reflection is the function of $A\cos\theta$. The optical power that is reflected by the secondary planet

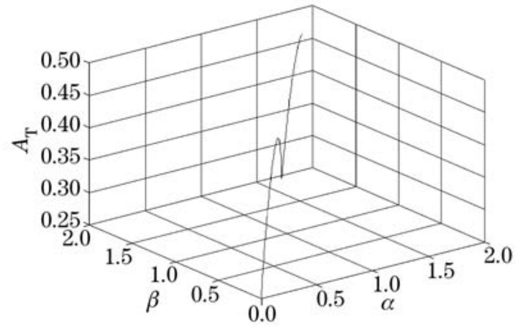

Fig. 3. Change of the projection area A_{T} with α and β.

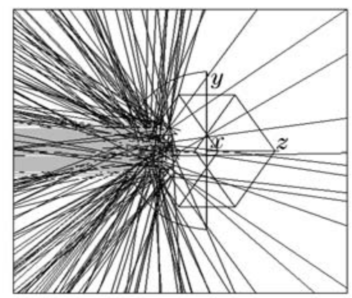

Fig. 4. Model of the simulation.

is the function of $A\cos\theta$, it changes as the effective area of projection changes. The factors affecting the optical power reflected by the secondary planet include the area of projection and the angle between surfaces of target and section of laser beam.

The radiant intensity reflected from the secondary planet is M, the radiant luminosity is L_e, $M = \pi L_e$, the secondary planet is radiant target of cosine with the radiant intensity of I_N[7]. The radiant quantity reflected from secondary planet is

$$P_{\mathrm{R}}^1 = \pi L_e A = \frac{I}{L^2} A\rho\cos\theta.$$

The radiant luminosity is

$$L_e = \frac{I}{\pi L^2}\rho\cos\theta.$$

The radiant intensity I_N is

$$I_N = \frac{I}{\pi L^2}\rho A\cos\theta.$$

The power received by the telescope is

$$\begin{aligned} P_{\mathrm{R}} &= I_0\Omega = I_N\Omega\cos\theta \\ &= \frac{I}{\pi L^2}\rho A\cos\theta\cos\theta\Omega \\ &= \frac{I}{\pi L^2}\rho A\Omega\cos^2\theta, \end{aligned} \tag{8}$$

where I_0 is the radiant intensity in the direction that secondary planet versus center of telescope, it is also in the direction against the incidence of laser beam; θ is the angle between normal of reflecting surface and direction of incidence laser beam, it is equal to the angle between reflecting surface and section of laser beam; Ω is the solid angle which the receiving telescope aims at secondary planet. The power P_R is the function of $A\cos^2\theta$. Because the solid angle Ω is the same, the radiant intensity reflected by the secondary planet is also the function of $A\cos^2\theta$. The radiant intensity reflected from the secondary planet changes with the effective area of projection of secondary planet and the angle between normal of secondary planet surface and direction of incident laser beam. The factors affecting the laser power received by the telescope include the effective area of projection and the angle between reflecting surface and section.

The distribution characteristic of radiant intensity and radiant emittance reflected by the secondary planet could be obtained by the Tracepro software in counting, and laser power received by the telescope was obtained.

The model shown in Fig. 4 was built for simulation. The zenith of secondary planet aimed at the center of laser beam, the absorbing rate of diffuse reflection surface was defined as 0.9. The laser beam which was 10000 m away from the secondary planet lighted the secondary planet, the laser power was 2×10^6 W, the surface of secondary planet gave the diffusing reflection. In the simulation, a hemisphere surrounded secondary planet, so the laser beams reflected from the secondary planet all passed through the surface of hemisphere. The distribution characteristics of radiant quantity and intensity were obtained and seen along the direction of incident laser beam.

One surface, two surfaces, and three surfaces of secondary planet were aimed at the center of laser beam in simulation. The figure of simulation of secondary planet reflection was obtained.

Surfaces of the secondary planet were all in reflecting, so the distributing area of radiant emittance was the same as the figure of surface of projection in the section of laser beam. The biggest radiant emittance was at the center of the laser beam, because the intensity of laser power was the biggest one at that point. The simulation results are shown in Fig. 5. Comparison between the simulation and theoretical values of radiant emittance (Table 1) shows that they are equivalent in quantity, the simulating results validate the characteristic of radiant quantity which is the function of $A\cos\theta$.

The distribution area of radiant intensity was the same as the figure of surface of projection in the section of laser beam, as shown in Fig. 6. The biggest radiant intensity was at the center of laser beam, because the intensity of laser power received by the secondary planet was the biggest one at that point. The values of simulation and theoretical analysis listed in Table 2 are equivalent in quantity, the simulating results validate the characteristic of radiant intensity which is the function of $A\cos^2\theta$.

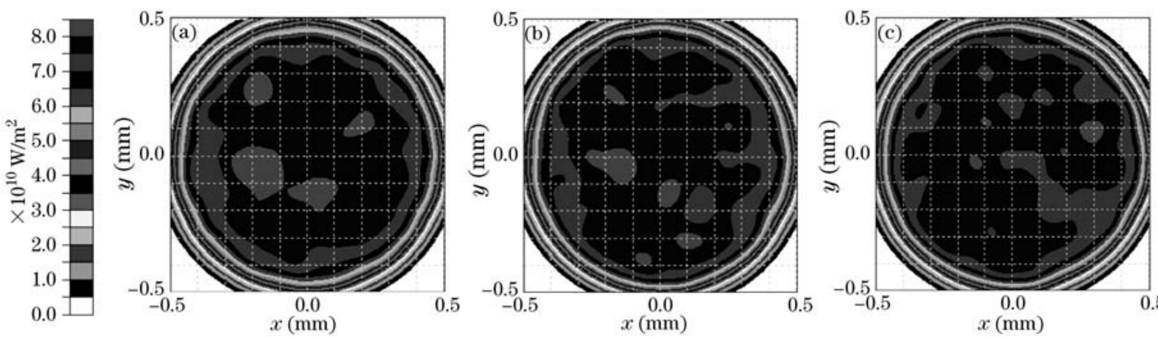

Fig. 5. Distribution figures of radiant emittance by the simulations of (a) one, (b) two, and (c) three surfaces are aimed at the center of laser beam.

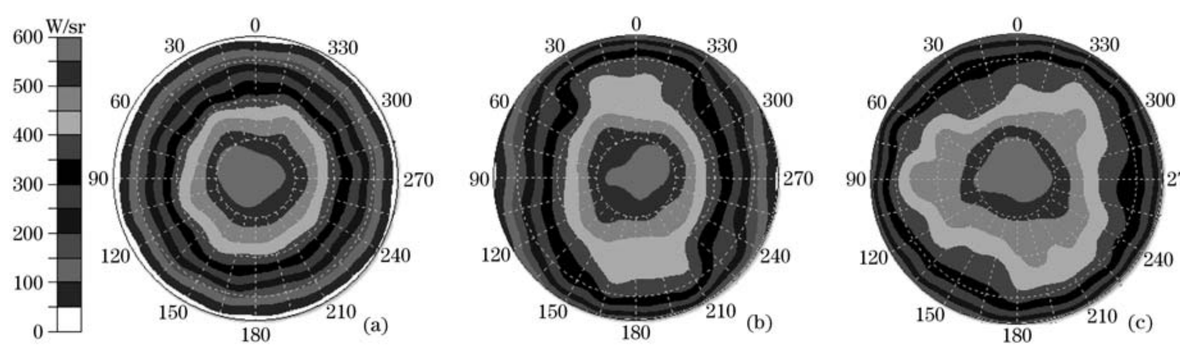

Fig. 6. Distribution figure of radiant intensity by the simulations of (a) one, (b) two, and (c) three surfaces are aimed at the center of laser beam.

Table 1. Theoretical and Simulation Values of Radiant Quantity of Secondary Planet Reflection

Number of Surfaces	$\cos\theta$	A	$A\cos\theta$	Simulation Value (W)	Theoretical Value (W)
One	1	0.25	0.25	1866	1591
Two	0.707	0.5	0.35	2253	2228.4
Three	0.577	0.75	0.433	2541	2752.6

Table 2. Theoretical and Simulation Values of Radiant Intensity of Secondary Planet Reflection

Number of Surfaces	$\cos\theta$	A	$A\cos^2\theta$	Simulation Value (W/sr)	Theoretical Value (W/sr)
One	1	0.25	0.25	588.76	563.46
Two	0.707	0.5	0.25	575.17	563.46
Three	0.577	0.75	0.25	584.59	563.46

In this paper, the smallest value that illuminating laser sends when the receiving system can detect the return signal is obtained. The estimating formula of the smallest power of illuminating laser of tracking, acquisition and pointing system in space is founded. The radiant intensity and quantity that the diffuse reflection target of secondary planet reflects are studied in theory and simulation. It is concluded that the distribution areas of radiant emittance and radiant intensity are the same as the figure of surface of projection in the section of laser beam. The factor affecting the radiant quantity of secondary planet is the effective area of projection, including the reflecting area of secondary planet and the angle between surface of projection and the reflecting surface. The factors affecting the radiant intensity are the area of projection in the section of laser beam and the angle between the direction of laser beam and normal line of reflecting surface. The radiant intensity and radiant quantity of secondary planet affect the laser power of the receiving system directly. The computing of the smallest value that illuminating laser sends when the receiving system can detect return signal, not only saves the resource, but also minimizes the cost. The distribution characteristics of radiant intensity and radiant quantity reflected by the diffuse reflection target of secondary planet are useful for measuring of the position and angle in space. The simulation results by the Tracepro software provide reference for the future experiment.

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