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Finite size panoramic optical system integrated design

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ABSTRACT

Aiming at the present situation of the panoramic target detection field, one laser target panoramic optical system on finite size is designed. The laser transmission optical system proposes a partition beam layout method, namely 360° omnidirectional detection can be realized by 6 fan-shaped light beams with $60^\circ \times 1^\circ$ field angle. The receiving system position and size can be determined based on calculation the transformation of the Gaussian beam through the lens. After the computing and optimizing the lens curvature radius and other optical parameters, the integrated design of the transmission and receiving optical system is completed. The system echo signal experiment is carried out, and the experimental results show the error of the actual value and theoretical value is less than 4.8%. The system works stably and the anticipated design effect is achieved.

1. Introduction

In the panoramic target detection field, such as the search and rescue, aerospace, robots, communication, war, security, and unmanned vehicles, the international commonly used detection system is the radio detection system, infrared detection system and laser detection system [1–3]. Because of many adverse target detection environment and strong electromagnetic interference, the radio detection system cannot work stably and normally [4,5]. The infrared detection system has many applications in the panoramic target detection fields, but it unable to realize the target detection effectively in complex landform, weather and other unpredictable conditions [6,7]. The laser detection system has the strong antijamming and target accurate control ability, and in some developed countries it is widely used in the military field at present [8–10]. However, it is difficulty to promote to civil field with the big equipment, expensive cost, some secret technology and other reasons. Therefore, it needs to design a low cost, small volume, high reliability, accurate orientation and quick response detection system in the world related civil field urgently. Aiming at the above problems, a laser target panoramic optical system on finite size was designed and the experimental results show the system echo signal error is small. The design idea, method and product in this paper have some extension value.

2. System design requirement

Based on the panoramic target detection project demand in the civil field, the research is carried out, which plans to design the system and realize the active panoramic detection in a cylinder structure with 100 mm diameter and some axial length. The system should have high time sensitivity, and the effective detection range is in 15 m. The structure should be simple, firm and work well in the great acceleration environment.

The active laser detection system includes the laser transmission optical system, receiving optical system and circuit system. Due to the finite size, the semiconductor laser is chose in this research. The transmission optical system should insure the emission beam has the appropriate optical path angle and beam field angle. In the receiving optical system, the detector device could have the certain detecting directivity and field angle, and get the target reflected laser beam to improve the detection signal-to-noise ratio with big light pass aperture. Therefore, the research must consider the target detection matching and the system space beam layout method. In this paper, the circuit system is not discussed.

Considering the above requirements, the detection system should be designed to achieve the following functions:

(1) Taking the system axis as the center, the laser transmission system emits laser beams to the 360° space, which form an "umbrella" shape. These laser beams is the "umbrella surface". If the distance between the target and the transmission system is less than a certain space range, the laser beam will detect the target and form the scattering.
(2) The angle of the umbrella surface and the axis can be changed from 60° to 90° depend on the actual demand.

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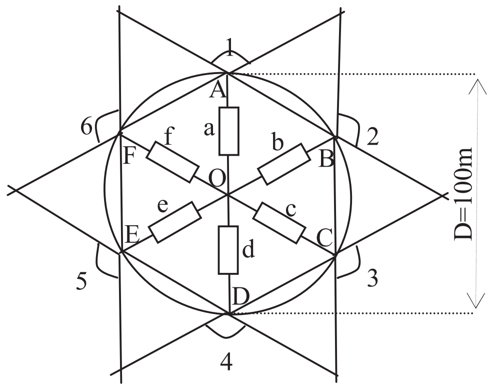


Fig. 1. Partition beam layout method.

(3) The receiving system is composed of optical receiving components and the corresponding wave length photoelectric detectors. The detector device could get the scatting signal from the 6 to 8 same angle space areas and estimate the target orientation.

3. Panoramic optical system layout designs

3.1. Laser beam layout method

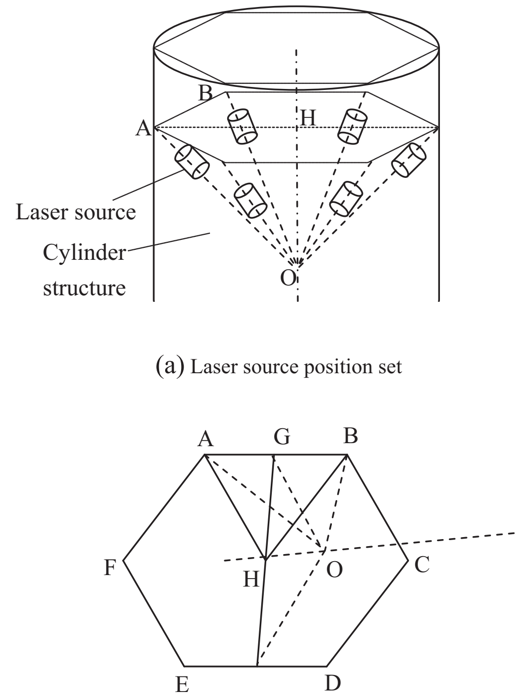
Considering the low cost and finite size, the partition detection method is proposed based on the existing research condition and project demand. The partition method divides the space into 4–8 area, and each area could realize the light source emission and echo signal receiving by the independent detector unit. In order to cover the entire circumference without non-blind area, these area boundaries could superpose or have small overlapping. The detector unit is an integrated transmission and receiving optical system and it will be discussed in the following paragraph.

Two questions should be considered before design. Firstly, the laser beam energy distribution characteristic is Gaussian distribution characteristic and the oversize field angle laser light source is not suitable. Secondly, considering the existing common laser product's size, the 100 mm diameter is quite small to ensure the beam emission direction and install several lasers, especially for columnar structure.

Compromising the two points, the circumference is divided into 6 areas; each area has an independent detector unit to realize the light beam emission and echo signal receiving. The single light source field angle is not so big and the lasers could be installed in the finite size based on the partition beam layout method. Under the high-speed detection condition, the detector reaction rate is the key to realize the system function. In order to make the response promptly, the research choose the high reaction rate detector and propose a new mechanism – an "umbrella" shape beam design to help the system discover the target early, which is shown in Fig. 1. In Fig. 1, the symbol a–f stands for the laser source in the system respectively; the symbol 1–6 represents the laser beam detection field angle on the 360° circumference; the symbol O is the intersection point of the laser sources on the system axis and the symbol A–F stands for the vertex on the cycle.

3.2. Calculate the laser source

The linear beam laser is chosen to cover the single area, whose field angle in one direction is 30–90° and in the vertical direction is less than 1°. This kind laser has the more possibility to satisfy the regional coverage and the echo signal power density. The laser panoramic system is different with the remote lidar system, the former's operating range is short and the target surface is complex, therefore the laser is not reflected from the target surface by the pointolite way.



(a) Laser source position set

(b) Field angle calculation inscribed hexagon

Fig. 2. Laser source position establishment and field angle calculation inscribed hexagon. (a) Laser source position set and (b) field angle calculation inscribed hexagon.

First step: calculate the laser energy threshold. If the target has the diffuse reflection characteristic and the laser power is P_T, the received echo power P_t is [11]

$$P_t = 4P_T \frac{A_t A_T}{\pi^2 R^4 \theta} \tau_T \tau_R \rho \tau_0^2 \quad (1)$$

where τ_T, τ_R, τ_0 and ρ are the emission optical system transmittance, the receiving optical system transmittance, the unidirectional propagation path transmittance, and the target reflectivity respectively, and A_t is the detector effective aperture area.

If the laser beams cover the target completely, then the presented target area is

$$A_T = \frac{\pi \theta^2 R^2}{4} \quad (2)$$

where R is the operating range and θ is the emission beam plane angle.

Due to the system operating range is not long, the atmospheric transmission attenuation could be ignore, that is $\tau_0 = 1$. P_t can be written as

$$P_t = P_T \frac{A_t}{\pi R^2} \tau_T \tau_r \rho \theta \quad (3)$$

Second step: estimate the laser source position and calculate the field angle. Fig. 2 shows the laser source position establishment and the field angle calculation inscribed hexagon structure. A–F is the hexagon vertex and O is some point on the system axis which is the identical point in Fig. 1. The symbol H is the inscribed hexagon center, and the symbol G is the center of line segment AB. In this design requirement ∠GOH is 60°, and ∠AOB is about 53.13° after calculation. Then the field angle can be set as 55°. Once the laser