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The application of active polarization imaging technology of the vehicle theodolite

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ABSTRACT

The vehicle theodolite has been the trend of the optical shooting range survey. While tracking and imaging of the long-distance dim targets have not been solved perfectly in this field, so this paper presents one active polarization imaging technology to find a way to deal with it. Firstly, we put forward a new active polarization imaging system with the lighting mode of circularly polarized laser and receives the reflected light by the mode of range-gating technique; secondly, deduces the pulse laser beam pointing algorithm; thirdly, describes the extended Kalman filtering algorithm to compensate the delay in the process and the calculation of the polarization angle, the attitude angle of flight target using single station cosine method and the depolarization of the circularly polarized laser. Finally, the result of this active polarization imaging technology which is simulated and analyzed in Simulink shows that the pointing precision can reach 0.0075 degrees. Then the analysis in this paper provide a theoretical basis for the application of the active polarization imaging technology in the field of the optical shooting range survey.

1. Introduction

With the rapid development of weapons, the requirements of the comprehensive ability of the test system have gradually increased, especially the adaptability, the maneuverability and the detection sensitivity of the long-distance dim target. These requirements have become the key technology and research trends in the measurement range [1–3].

The working mode of landing measurement is used by the conventional photoelectric theodolite, and the leveling of the theodolite must be carried out strictly before work [4,5]. To satisfy the needs of the maneuverability of the measurement, the vehicle theodolite is usually used as an active optical measuring device [6–8]. Its main advantage is that the layout is flexible, and is not limited by time and space. Except this, the operating distance and imaging quality of the optical device must be taken into account. In the weapon shooting range, the complex environment conditions, such as fog, dust, cloud, the detection surface temperature, the brightness distribution and other factors will affect the visible and infrared imaging detector, so how to effectively improve the photoelectric theodolite range and the image quality becomes a key to the vehicle theodolite [9–13]. Laser lighting has the advantages of clear imaging, high contrast, long-distance detection, and not affected by the ambient light [14]. In the low Signal-to-noise ratio (SNR or S/N) and low visibility environment, the polarization imaging detection has many advantages over traditional imaging detection, such as suppressing the noise of the background, improving the image contrast, highlighting the target details, improving the detection distance, enhancing the ability of the target recognition and detection and etc. [15–17].

Aiming at the above problems, this paper proposes one new theodolite measuring method which is based on the attitude system positioning (Positioning and Orientation System, POS). In this paper, an active polarization imaging optical system with dual-field transceiver is described and the polarization angle can be obtained by the target attitude calculated by single point cosine and the beam direction angle calculated by the moving target trajectory and the theodolite pose information. The results of the research and design in this paper comprehensively consider the application of the project, which lays a technical foundation for the follow-up study.

2. Design of an active polarization imaging optical system with dual-field transceiver

The active polarization imaging optical system utilizes an integral design with the common aperture transceiver. It consists of a primary and secondary mirror, a zoom switcher group, a transmitter–receiver isolation device, a laser light source, a long and short focus imaging lens group and a receiving detector, as shown in Fig. 1.

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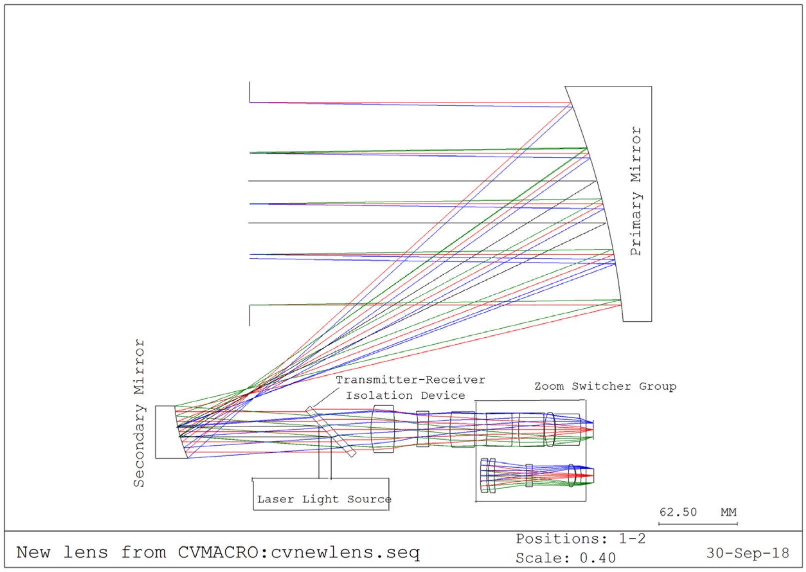

Fig. 1. The active polarization imaging optical system with dual-field transceiver.

Table 1
The optical system parameters.

Parameters	Values	Parameters	Values
Divergence angle	1 mrad	Receiving focal length	400/800 mm
Spot diameter	4 mm	F-number	5
Beam expansion ratio	5×	Detector parameter	1280 × 1024, 6.7 μm

The primary and secondary mirror is used to broaden the laser in order to improve target detection ability by enlarging the receiving aperture and increase the collimation by reducing the laser divergence angle.

The zoom switcher group is used to realize the long distance lighting by collimating the laser beam. It uses two confocal paraboloidal mirrors and off-axis combination to avoid the influence of central obscuration of energy. In addition, the structure system of coma is zero, then it has a larger field of view, which reduces the correction pressure of the aberration of the post imaging objective lens group.

The transceiver isolator is used to isolate the emitting and the receiving laser signal by the polarization control method which is according to the different polarization states between the two laser signals. Through the Brewster beam splitter and the quarter-wave plate, the emitting laser can be reflected and the receiving laser can be passed.

The long and short focus imaging lens group is used to realize the large field search and small field of high resolution imaging fast switching by cutting the length of the focal switch system.

According to the above contents, one new optical system is designed and the parameters of it are shown as the Table 1.

The MTF (Modulation Transfer Function) of the switch-zoom optical system at the spatial frequency of 74l p/mm is greater than or equal to 0.4. The imaging quality is good enough to satisfy the clear imaging of the target. The MTF curves of the switch-zoom optical system are shown as Fig. 2.

The design results of zoom switcher group reach the diffraction limit and the wavefront aberration is close to zero, which can meet the requirements of the expanding system. The wavefront aberration curve of the laser expanding system is shown in Fig. 3.

3. The high precision pointing algorithm of the vehicle theodolite

When the trailer-mounted theodolite measuring, the vertical axis error of the theodolite which is caused by the rigidity and the gap of the mechanism, is changed by the external disturbance.

In order to improve the adaptability and mobility of the theodolite, the position and posture information of the theodolite is measured in real time by POS installed on the theodolite base.

In the guidance mode of the target, according to the longitude and latitude, elevation information and attitude information of the theodolite, the real-time trajectory of the measured vehicle is converted to the azimuth and elevation angle of the theodolite by the corresponding coordinate transformation. The specific process is as follows:

Assuming that the trajectory of the measured aircraft containing longitude, latitude and height can be regarded as (λ_p, L_p, h_p), the real-time data value containing longitude, latitude and height of the theodolite for POS output can be regarded as (λ_T, L_T, h_T), the two information can be converted into (x_T, y_T, z_T) and (x_p, y_p, z_p) in the space coordinates. The derivation process is as follows:

$$\begin{aligned} X_e &= (N+h)\cdot\cos L\cdot\cos\lambda \\ Y_e &= (N+h)\cdot\cos L\cdot\sin\lambda \\ Z_e &= (N\cdot(1-ee)+h)\cdot\sin L \\ N &= (long\_R)^2 / sqrt\left((long\_R)^2\cdot\cos^2 L+(short\_R)^2\cdot\sin^2 L\right) \end{aligned} \tag{1}$$

where (λ, L, h) denotes the longitude, latitude, height of the target to be converted;

(X_e, Y_e, Z_e) denotes the coordinates in space three-dimensional coordinate system (WGS84 coordinate system);

$long\_R$ denotes the radius of the earth's long axis;

$short\_R$ denotes the radius of the earth's short axis;

ee denotes the square of the first eccentricity rate;

N denotes the intermediate variable;

Then the unit line-of-sight vector of the theodolite D can be calculated by the coordinates of the two datas.

$$D=\left(\frac{x_T-x_P}{L},\frac{y_T-y_P}{L},\frac{z_T-z_P}{L}\right) \tag{2}$$

Then $L=\sqrt{(x_T-x_T)^2+(y_T-y_P)^2+(z_T-z_P)^2}$ denoting the absolute distance between the measured point and the theodolite can be calculated.

The theodolite base is installed on the vehicle base, according to the relative angular position relation between the vehicle body coordinate system and the geographic coordinate system, the attitude angle of the vehicle body can be determined [18]. According to the azimuth angle, pitch angle and roll angle of the vehicle, the unit direction vector in the geographic coordinate system could transformed to the theodolite base