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Ground target localization algorithm for semi-active laser terminal correction projectile

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Abstract

A target localization algorithm, which uses the measurement information from onboard GPS and onboard laser detector to acquire the target position, is proposed to obtain the accurate position of ground target in real time in the trajectory correction process of semi-active laser terminal correction projectile. A target localization model is established according to projectile position, attitude and line-of-sight angle. The effects of measurement errors of projectile position, attitude and line-of-sight angle on localization accuracy at different quadrant elevation angles are analyzed through Monte-Carlo simulation. The simulation results show that the measurement error of line-of-sight angle has the largest influence on the localization accuracy. The localization accuracy decreases with the increase in quadrant elevation angle. However, the maximum localization accuracy is less than 7 m. The proposed algorithm meets the accuracy and real-time requirements of target localization.

Keywords: Semi-active laser guidance; Terminal correction projectile; Target localization; Localization accuracy

1. Introduction

Using reconnaissance system to obtain the exact coordinates of ground target and providing the target location for weapon systems timely has become an efficient combat mode. A reconnaissance system is used to locate a target, and the target localization information is loaded to an onboard computer before launching a trajectory correction projectile. Currently, UAV [1–3], airborne electro-optical platform [4], and airborne radar or ground radar [5–7] have been used for ground target localization. The localization accuracy of all the localization methods is related to position accuracy of carrier itself and target detection accuracy.

On the battlefield the localization methods mentioned above have a certain target localization accuracy, but they have some security issues. For example, when an unmanned aerial vehicle (UAV) electro-optical detection platform (EODP) is used to locate a target, there are excessive measurement error factors, and it is difficult to analyze the localization accuracy; the localization methods by radar and GPS are susceptibly influenced by electromagnetic interference, and the cost is relatively high; localization method by reconnaissance aircraft is easy to expose to the target. In order to reduce the difficulties and risk of reconnaissance, an autonomous ground target localization method for semi-active laser terminal correction projectile is proposed in the present paper. In the proposed method, the relationship between projectile and target location is derived by combining the onboard GPS measurement data with the laser spot signal received by laser detector, and then the target location is calculated exactly. The influence of measurement errors on the localization accuracy obtained by the localization algorithm at different launching angles is analyzed through Monte Carlo method. The results show that the localization accuracy is higher in the case of small launching angle, and the influence of line-of-sight angle measurement error on the localization accuracy is very small. The method realizes self-localization for ground target without other reconnaissance system.

2. Target localization method

The operating principle of semi-active laser terminal correction projectile is that a laser designator is used to irradiate a target, and then a laser spot signal reflected from the target is received by a laser detector, as shown in Fig. 1; a control

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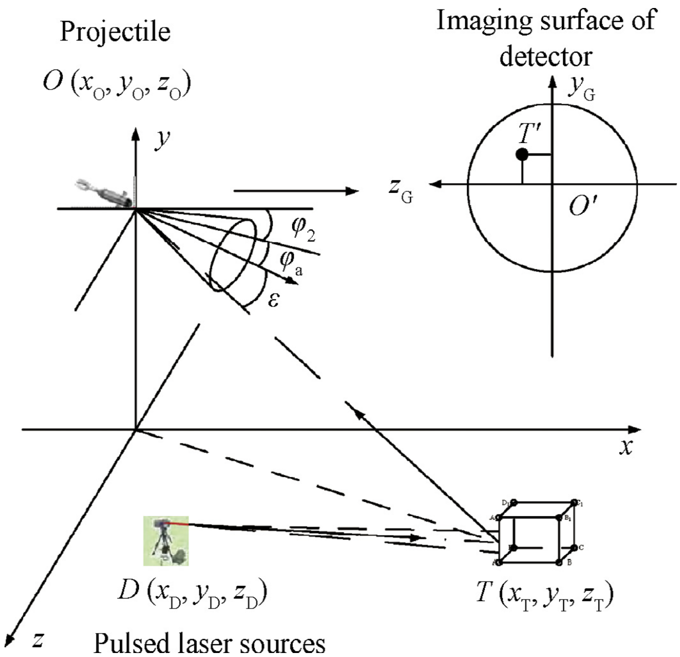

Fig. 1. Working principle of semi-active laser terminal correction projectile.

command is generated based on the reflected signal as input; and finally, according to the control strategy, the trajectory error is corrected by a control force produced by an actuator in projectile.

Laser spot signal reflected from target can be measured directly by laser detector, and then the line-of-sight (LOS) angle can be obtained, namely the angle between the projectile axis and line-of-sight. In this study, the target coordinate is derived based on line-of-sight angle, projectile position and speed.

2.1. Measurement model of laser detector

A detector of strapdown seeker is completely fixed to a projectile. An imaging point of target on the image plane is obtained after a laser spot signal is received by laser detector. The ground frame O-XYZ and the body frame O-$X_1Y_1Z_1$ are defined in [8], and the image frame O'-$X_gY_gZ_g$ is transformed from the body frame, as shown in Fig. 2.

In the ground frame, the projectile coordinate is noted as $O(x_o, y_o, z_o)$, and the target coordinate is noted as $T(x_t, y_t, z_t)$. The target coordinate in body frame is

$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} = \begin{bmatrix} \cos\varphi_2\cos\varphi_a & \cos\varphi_2\sin\varphi_a & \sin\varphi_2 \\ -\sin\varphi_a\cos\gamma - \sin\varphi_2\cos\varphi_a\sin\gamma & \cos\varphi_2\cos\varphi_a - \sin\gamma\sin\varphi_2\sin\varphi_a & \sin\gamma\cos\varphi_2 \\ \sin\gamma\sin\varphi_a - \cos\gamma\sin\varphi_2\cos\varphi_a & \sin\gamma\sin\varphi_a - \cos\gamma\sin\varphi_2\cos\varphi_a & \cos\gamma\cos\varphi_2 \end{bmatrix} \begin{bmatrix} x_t - x_o \\ y_t - y_o \\ z_t - z_o \end{bmatrix} \quad (1)$$

where φ_a, φ_2 and γ are the elevation angle, projectile axis azimuth angle, and roll angle of projectile [8], respectively. f is expressed as the focal length of lens, as shown in Fig. 2. In the image frame, $x_g = f$ is a constant since the image plane is placed on the focal plane. According to the imaging geometric relationship of laser spot, the imaging point of target in the image frame is (y_g, z_g)

$$\begin{bmatrix} x_g \\ y_g \\ z_g \end{bmatrix} = \frac{f}{x_1}\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} \quad (2)$$

The imaging point of target in image frame can be obtained by using Eqs. (1) and (2). In Fig. 2, Point T is the target point, and Point T′ is the laser spot on the detector image surface. Then the line-of-sight angle can be obtained by the following formula

$$\varepsilon = \arctan\left(\sqrt{{y_g}^2 + {z_g}^2} \Big/ f\right) \quad (3)$$

The magnitude of line-of-sight angle reflects the deviation of projectile longitudinal axis from line-of-sight.

2.2. Estimation method of projectile attitude angles

In order to realize the target localization, the projectile attitude angles need to be obtained at first. For flight projectile, the angle between projectile longitudinal axis and projectile velocity is small, the deviation of trajectory from shooting surface is also small, and therefore the elevation angle φ_a and azimuth angle φ_2 can be estimated as follows

$$\begin{cases} \varphi_a \approx \theta_a + \delta_1 \\ \varphi_2 \approx \psi_2 + \delta_2 \end{cases} \quad (4)$$

where θ_a and ψ_2 are velocity elevation angle and velocity azimuth angle, respectively; and δ_1 and δ_2 are angle of attack and the sideslip angle, respectively. The velocity elevation angle and velocity azimuth angle [8] can be obtained according to the definition

$$\begin{cases} \theta_a = \arctan\left(v_y / v_x\right) \\ \psi_2 = \arctan\left(v_z \Big/ \sqrt{v_x^2 + v_y^2}\right) \end{cases} \quad (5)$$

where v_x, v_y, and v_z are the velocity components in the base frame [8], which can be measured by onboard GPS in real time. External ballistics theory [9] shows that, for non-rolling and fin-stabilized projectile, its angle of attack is large early in the ballistic flight path but then stabilizes further along the projectile flight path. Its angle of attack can be approximated to 0° in the final stage of flight. Therefore, θ_a and ψ_2 can be approximated to φ_a and φ_2, respectively, based on the