Research on Aiming and Tracking Ability Evaluation Model of Laser-guided Missile

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Abstract. Laser guidance is a continuous process, during which a lot of operational data and corresponding changes are generated. Aiming at the live-fire drill shooting training and assessment evaluation of a certain type of laser-guided missile, this paper analyzes the principle of laser guidance, studies the weighting system of the information field based on the importance of characteristic intervals, integrates and processes the data and outputs the aiming effect picture and sheet, and constructs the aiming and tracking ability evaluation model. Stationary targets and moving targets are tested respectively, and the verification model can realize the calculation of laser information field, the integration of coordinate data, the output of aiming effect diagram, and the evaluation of the shooter's aiming and tracking ability expressed in a percentage system. The model realizes data collection, integration and processing based on MATLAB software, and builds graph and table output ports, which can realize low delay processing of a large amount of short-term data.

Key words: Laser guidance; Evaluation model.

1. Introduction

Laser guidance technology is widely used in weapon systems such as UAV-borne missiles, helicopter-borne missiles, and artillery-launched missiles due to its advantages of high guidance accuracy, strong anti-interference ability, and simple structure. At present, laser-guided missile mainly adopt two guidance technologies: semi-active laser guidance and laser beam-riding guidance. Taking laser beam-riding guidance technology as an example, the shooter’s aiming and tracking ability is the most important and critical factor that determines the shooting accuracy. From the perspective of live-fire drill, we study the basic principles of laser beam-riding guidance technology, build a laser guided missile aiming and tracking capability evaluation model, and use stationary targets and moving targets for experimental verification.

2. Principle of Laser Beam-Riding Guidance

The laser beam-riding guidance system consists of a guidance system and a control system on missile. The guidance system transmits the encoded laser information field to the target through the guidance instrument. The missile flies in the laser information field. The control system on missile receives the laser information and decodes it. It measures the direction and size of the missile’s deviation from the line of sight and forms control commands. Actuator adjusts its attitude according to the control
commands and controls the missile to correct its flight trajectory toward the line of sight until it hits the target.

The information field modulation disc in the guidance instrument rotates clockwise at a fixed frequency, the width of the linear area of the code channel is \( \Delta R \), and the encoded information field contains five frequencies: \( f_1, f_2, f_3, f_4, f_5 \). Within a time period \( T \), \( f_1 \) and \( f_2 \) represent the coordinate position of the missile's yaw direction, \( f_3 \) and \( f_4 \) represent the coordinate position of the missile's pitch direction, and \( f_5 \) is an intermediate variable introduced for anti-interference. The optical system begins to zoom 1s after the missile fired, and the diameter (D) of the information field at the cross section of the missile’s tail remains fixed before hitting the target. According to the guidance characteristics of laser beam-riding guided missile and the coding method of the laser information field, there is a square area with a side length of \( L \) in the center of the cross section of the information field. When the missile is flying in this area, the missile is not be controlled, that is to say, the missile is considered to be flying along the line of sight, so define this area as the uniformly distributed area of missile. The corresponding relationship between the laser information field of the missile’s tail section and the modulation disc is shown in figure 1.

When the missile is at position A in the laser information field, its coordinates relative to the center of the interface can be obtained by formulas (1) and (2):

\[
\Delta x = \frac{\tau_1 - \tau_2}{T/2} \times \frac{\Delta R}{2} \times \alpha \\
\Delta y = \frac{\tau_3 - \tau_4}{T/2} \times \frac{\Delta R}{2} \times \alpha
\]  

In the formula, \( \Delta R \) is known, \( \alpha \) is the projection magnification factor, and the constant \( \tau_1, \tau_2, \tau_3, \tau_4 \) are the duration of the \( f_1, f_2, f_3, f_4 \) received by the missile tail laser receiver, respectively. Based on the basic principles of guidance and formulas (1) and (2), the laser information of the information field can be converted into the coordinate information of the missile in the information field, which provides basic data for the establishment and calculation of the aiming and tracking capability evaluation model.

3. Evaluation model construction

The missile hit accuracy is affected by systematic and random errors. Systematic errors are related to the equipment situation and environment, and must exist and have a constant error value. Random errors
are related to shooter’s aiming and tracking ability. The error values fluctuate greatly and even affect hit accuracy. The aiming and tracking ability evaluation model is constructed based on actual combat environment conditions, and the shooter's aiming and tracking ability is correctly evaluated through this model.

3.1. Hardware composition and design
Design training venues according to training subjects and training content. For stationary targets, a 1:1 armored vehicle model is adopted. The laser receiver control system and signal transmission device are installed on the back of the model. The main laser receiver is installed in the center of the front of the model. An auxiliary laser receiver is installed 1 meter directly above the main receiver. The receiver installation position relationship is shown in figure 2.

![Figure 2. Laser receiver position](image)

The function of the laser receiver control system is to receive the laser encoding information of the position in the guidance information field and decode and output the corresponding coordinate information. The coordinate information output by the main receiver is used for the evaluation of the shooter's aiming and tracking ability, and the coordinate information output by the auxiliary receiver is used to calibrate the coordinate projection ratio of the information field. The signal transmission device transmits the coordinate information output by the main receiver and the auxiliary receiver to the evaluation model.

For moving targets, slide rails are installed under the armored vehicle model so that it can move according to control instructions. The other design ideas are the same as those of stationary targets. A pressure sensor and a signal transmission device are installed on the missile "fire" button on the missile launching part to record the launch time of the missile and transmit it to the evaluation model.

3.2. Hardware composition and design
In the plane of target, the installation position of the main laser receiver (the target center) is used as the origin to establish the reference coordinate system $XOY$; In the missile tail cross section plane, intersection of the center line of the information field and the cross section is used as the origin to the missile coordinate system $X'OY'$; For the target plane, take the intersection of the center line of the information field and the plane of the target board as the origin to establish a moving coordinate system $X''O''Y''$. As shown in figure 3.

![Figure 3. Coordinate system](image)
Suppose that the flight speed of the missile after firing is $V$, the distance between the target and launching point is $S$, the coordinate information received by the main receiver at a certain time $t_0$ is $(x_0', y_0')$, the coordinate of the main receiver in the coordinate system $X'Y'$ is $(x_0^*, y_0^*)$, the missile (information field centre line) in the coordinate system $XOY$, the coordinates is $(x_0, y_0)$, and the coordinate information received by the auxiliary receiver is $(x_0^*, y_0^*)$. The coordinates $(x_0', y_0')$, $(x_0^*, y_0^*)$, $(x_0, y_0)$ can be obtained by formulas (3), (4), and (5).

\[
\begin{align*}
    x_0 &= x_0^* - x_0'^* \frac{\Delta R}{2} \cdot \frac{S}{V_{x0}} \\
    y_0 &= y_0^* - y_0'^* \frac{\Delta R}{2} \cdot \frac{S}{V_{y0}} \\
    x_0 &= x_0^* \cdot k \\
    y_0 &= y_0^* \cdot k \\
    x_0 &= -x_0' = -x_0^* \frac{V_{x0}}{S} \\
    y_0 &= -y_0' = -y_0^* \frac{V_{y0}}{S}
\end{align*}
\]

Among them, $k = \frac{1}{\sqrt{(f_0 - x_0^*)^2 + (g_0 - y_0^*)^2}}$, when $k=1$, $x_0 = x_0^*$, $y_0 = y_0^*$, the diameter of the information field in the target section is $D$, which is the intersection of the missile and the target. The area division of the target and reference coordinate system is shown in figure 4. The location relationship and corresponding scores of each area are shown in Table 1.

![Figure 4. Target plane area division](image)

**Table 1.** The location relationship of each area

| Area | A   | B   | C   | D   | E   |
|------|-----|-----|-----|-----|-----|
| Assign points | 100 | 99-80 | 79-61 | 60 | 0 |

According to the position relationship of the divided area and the setting of score assignment, write a program using MATLAB software, the input aiming point coordinates are sequentially judged, and the output the corresponding scores $Q_j$.

4. **Evaluation of the aiming ability of stationary targets**

When the missile hit stationary target, the shooter is required to keep stable aiming at the target. Missile flight time varies with the distance of the missile and the target. It is based on the basic principle of the importance weighting method of the characteristic interval, combined with the characteristics of the
laser information field and the on-board steering gear adjustment delay, etc. In specific circumstances, the flight time is divided into segments and weighted respectively as follows:

a. The initial stage \((t_0 = 0 \sim 1)\). At this stage, the information field is initially formed, it is not zoomed. It has a low effect on the entire missile flight. It is given a weight of 5%. The score \((Q_0)\) at the time \(t=0\) s plays a role in the adjustment coefficient for the entire aiming process;

b. Early stage of guidance \((t_0 = 1 \sim t/3)\). The information field is zoomed, the missile has a large adjustment range, and the flight is unstable, given a weight of 20%;

c. The middle section of guidance \((t_0 = t/3 \sim 2t/3)\). The information field is stable, the missile flight is stable, keep the stable aiming, given a weight of 30% ;

d. End of guidance \((t_0 = 2t/3 \sim t)\). There is a certain delay in missile flight adjustment. At this stage, the aiming accuracy has a greater impact on the missile hit accuracy, and 45% weight is assigned.

The ability to aim at a stationary target can be obtained by formula (6).

\[
P_s = Q_s = \frac{Q_0}{100} \times \left( \sum_{j=1}^{100} Q_j \times 5\% + \sum_{j=101}^{1000} Q_j \times 20\% + \sum_{j=1001}^{2000} Q_j \times 30\% + \sum_{j=2001}^{3000} Q_j \times 45\% \right)
\] (6)

5. Evaluation of aiming and tracking ability of moving targets

When the missile hit a moving target, the shooter is required to keep tracking the target smoothly. The weapon performance index requires that the target's lateral velocity is not more than 60 km/h. The target is installed on a horizontal slide rail, the target board is set to move in one direction or reciprocating at the speed of 0~60 km/h.

During aiming and tracking training of moving targets, the shooter judges the moving direction and size of the target and adjusts the scope. The sensor installed on the scope can obtain the angular velocity of the shooter adjusting the scope \(\omega\).

Suppose the target board moving speed is \(V_m\), the distance between the target board and tank is \(S\), then the standard angular speed of the sight rotation is \(\omega_0 = V_m / 3.6S\) rad/s, The deviation of \(\omega\) relative to \(\omega_0\) reflects shooter's ability of tracking moving targets, and the coordinate data reflects shooter's ability of aiming target. Comprehensively, shooter's ability of aiming and tracking moving targets can be obtained.

The processing of the coordinate data is the same as stationary target training, and the score \((Q_m)\) is obtained, The deviation of \(\omega\) relative to \(\omega_0\) is expressed by \((1 - \frac{\omega_0 - \omega}{\omega_0})\). Shooter's ability of aiming and tracking moving target can be obtained by formula (7).

\[
P_m = Q_m \times \left(1 - \frac{\omega_0 - \omega}{\omega_0} \right)
\] (7)

6. Test and conclusion

Laser beam-riding guidance missiles can be used to hit stationary and moving targets. The starting point of the process of aiming and tracking the target is determined by the pressure sensor, and the end of the time is determined by the cooperation of the auxiliary receiver and the main receiver. During training and assessment, the target characteristics are distinguished, and the shooter's ability to aim and track stationary and moving targets is given percentage points and five level evaluations: excellent, good, medium, passing, and failing.

The evaluation model is tested and verified, and five sets of data in a certain aiming and tracking training are selected. The missile flight speed is known \(V=300\) m/s, and the distance between the target
plate and the muzzle \( S=4000 \) m, the missile flight time \( t=40/3 \) s. The graph of the shooting process is shown in Figure 5, and the output evaluation results are shown in Table 2.

![Figure 5. Multiple shooting process](image)

**Table 2. Evaluation results**

| curve | Aiming point map | score | evaluation |
|-------|------------------|-------|------------|
| (1)   | ![Aiming point map](image) | 100   | excellent  |
| (2)   | ![Aiming point map](image) | 96.3  | excellent  |
| (3)   | ![Aiming point map](image) | 87.7  | good       |
| (4)   | ![Aiming point map](image) | 76.4  | medium     |
| (5)   | ![Aiming point map](image) | 0     | failing    |
The shooting process can intuitively reflect shooter's change of the aiming target; the aiming point graph can intuitively reflect the shooter's aiming deviation and change trend; the score and evaluation degree can give the numerical level of the shooter's aiming ability. The test results show that the model conforms to reality and can give a quantitative evaluation of the shooter's aiming and tracking ability. It is of great significance for the training and evaluation of the shooter's aiming and tracking ability and the establishment and improvement of the laser-guidance missile actual combat training system.

This paper studies and solves the difficult problems of shooters’ laser-guidance missile aiming and tracking ability training and evaluation, and has achieved the following results:

a. Study the principle of encoding and decoding of laser information field, and design the transformation process of "laser information→electric pulse information→coordinate information";

b. Constructing an evaluation model for the shooter's aiming and tracking ability, and establishing an evaluation system for stationary targets and moving targets respectively, which is of great significance for improving training effects and reducing training costs;

c. The current model also has problems such as large amount of calculation, short coordinate sampling interval, and low discrimination. The next step is to improve the above problems.

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