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Trajectory Parameter Generation and Simulation Analysis of Missile

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Abstract

Trajectory tracking is the core problem in ballistic missile defense system, that is, modeling the trajectory of ballistic missile. Trajectory modeling is the premise and foundation of simulating the trajectory of ballistic missile and studying the trajectory tracking of ballistic target. According to the mission requirements of surface-to-surface missiles, this paper makes an in-depth study on the trajectory optimization design of surface-to-surface missiles. The main work includes: First, analyze the characteristics and movement rules of the surface-to-surface missile flight trajectory, establish the differential equations of the missile motion in active phase, free phase and reentry phase, and analyze the main parameters that affect the missile trajectory, and establish the flight control program and the multi-objective optimization model of the missile, including the coordinate conversion module, the standard atmosphere module, the gravity module, and the missile characteristics. When the missile characteristics can't meet the target normally, the final result will be obtained.

Keywords

Missile Trajectory; Missile Calculation Algorithm; Imitate.

1. Introduction

In the process of live-fire training of weapons, there is a huge problem of financial and manpower consumption. In order to improve the training efficiency of ballistic missile shooters, a virtual missile trajectory target training system is designed by virtual simulation. Ballistic missile is not only the embodiment of a country's scientific and technological strength and military strike force, but also the symbol of military deterrence. Generally speaking, the operational mission of missile weapons is actual combat and deterrence[1]. As missile weapon is the crystallization and embodiment of modern high technology, it has outstanding characteristics different from general offensive weapons, especially its remarkable characteristics of great power, long range, high precision and strong penetration ability, which makes it a weapon with super offensive and powerful deterrence, and it has become the pillar to maintain strategic balance, the protagonist and "killer" of asymmetric warfare, the main battle equipment of information warfare, the necessary weapon to achieve precise warfare, the lifter of combat capability of various weapon platforms, and the main interception of modern combat defense systems[2-4].

Trajectory tracking is the core problem in ballistic missile defense system. The motion model of ballistic missile with multi-stage booster is modeled, and the influence of propulsion, air resistance, gravity and external force on the acceleration of ballistic target is analyzed in detail. This paper introduces the core problem in the simulation trainer of missile system: solving the trajectory of missile. Shooter launches the missile after aiming at the target, and inputs high and low deviation angles and horizontal deviation angles into the model system. The spatial position of the missile is deduced, the solution of the missile trajectory is realized, and a realistic training environment is provided for the shooter. Finally, the trajectory simulation process of the ballistic missile is further

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described. The flight trajectory of ballistic missile with three-stage booster is obtained by simulation experiment, and the influence of multi-stage booster on the change of velocity and acceleration is analyzed. This is of great significance to the research of long-range ballistic missile tracking.

2. Research on the Motion of Missile Trajectory

2.1 Motion Model and Composition of Missile Trajectory

The flight of ballistic targets is usually divided into three stages:

Active phase, free phase and reentry phase give the flight phases of ballistic missiles.

Table 1. Segments of ballistic model and its stress situation

	Active segment	Free segment	Reentry segment
Flight stage	From the point of origin To the shutdown point	Outside the atmosphere of the earth, the flight operator of the ballistic target coincides with the Kepler orbit.	From entering the atmosphere To hit the ground Mark up
Stress situation	Gravity, propulsion, air resistance and external force.	Heart force and external force	Geocentric attraction, air resistance and external force

The motion model of the trajectory of the target system is established in a coordinate system fixed at the center of the earth. The target position is $p=\left[p_x, p_y, p_z\right]$ and the speed is $v=\left[v_x, v_y, v_z\right]$. Through the acceptance analysis of the missile trajectory, the motion formula 1-2 of the missile trajectory target can be established:

$$p = v \tag{1}$$

$$v = a_T + a_D + a_G + a_C \tag{2}$$

In Formula 1-2, the acceleration of a ballistic target is mainly divided into four items: acceleration a_T caused by propulsion, acceleration a_D caused by air resistance, acceleration a_G caused by gravity, and acceleration a_C caused by external forces (Coriolis force and centrifugal force). Surface-to-surface ballistic missile is usually composed of propulsion system, warhead, body structure and guidance system. Propulsion system is a device that provides power for missile flight. It is mainly composed of engine and propellant supply system, and its core is the engine. Surface-to-surface ballistic missiles generally use solid or liquid rocket engines. Tactical missiles require good maneuverability and quick response capability, so most of them choose solid rocket engines. Influenced by the propulsion force of booster, air resistance, gravity and external force, the motion model of ballistic missile with multi-stage booster is deduced, and the trajectory simulation process of ballistic missile is given[5]. The specific missile structure diagram and hardware virtual diagram are shown in Fig. 1:

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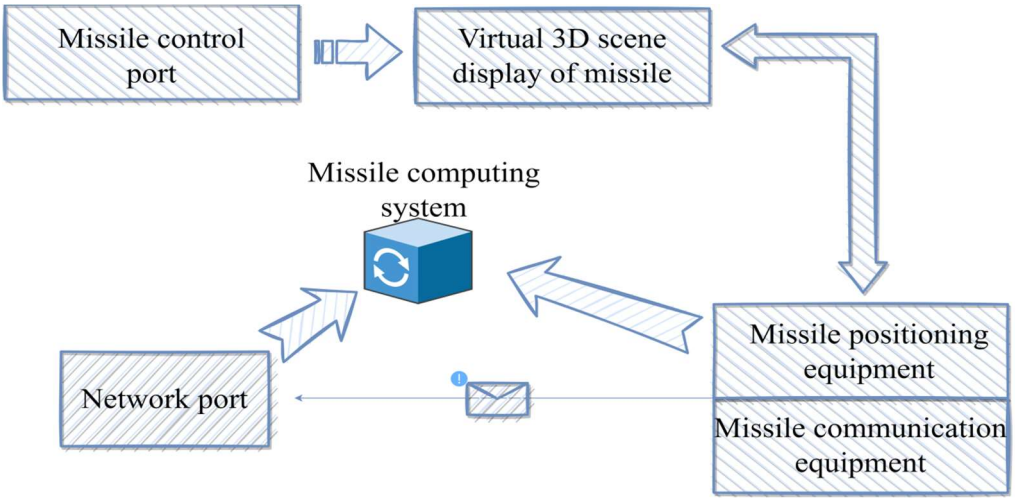

Fig.1 Missile system calculation diagram

Working principle of the system: In the whole system, all devices are connected to the same LAN, and information exchange among all devices is carried out wirelessly. The positioning device collects the current attitude information of the missile launcher, mainly including yaw angle, pitch angle and roll angle.

2.2 Test Results and Conclusions

Warhead is a component used to destroy and destroy targets, kill effective forces, and complete combat missions. Generally, it is arranged at the head of missiles, and mainly consists of shell, stuffing, detonating device and safety device. According to different targets, different types of warheads can be allocated. Most strategic warheads are charged with nuclear weapons. It can be a single warhead or multiple warheads[6]. There are three types of multi-warheads: cluster, sub-guided and mobile. i indicates that the missile is in the k stage of propulsion at i hours. The calculation of the total weight W_{total}^{k} of the missile at k refers to the single-stage booster missile, and the formula 3: $W_{\text{total}}^{k} = W_{total}^{o} + W_{P3} + W_{S3} + W_{P2} + W_{S2} + W_{P}\frac{t_k}{t_{hourm}^{1}}$ (3) is obtained. In particular, the calculation of W_{total}^{k} depends on the i propulsion stage of the missile at k, as shown in Fig. 2:

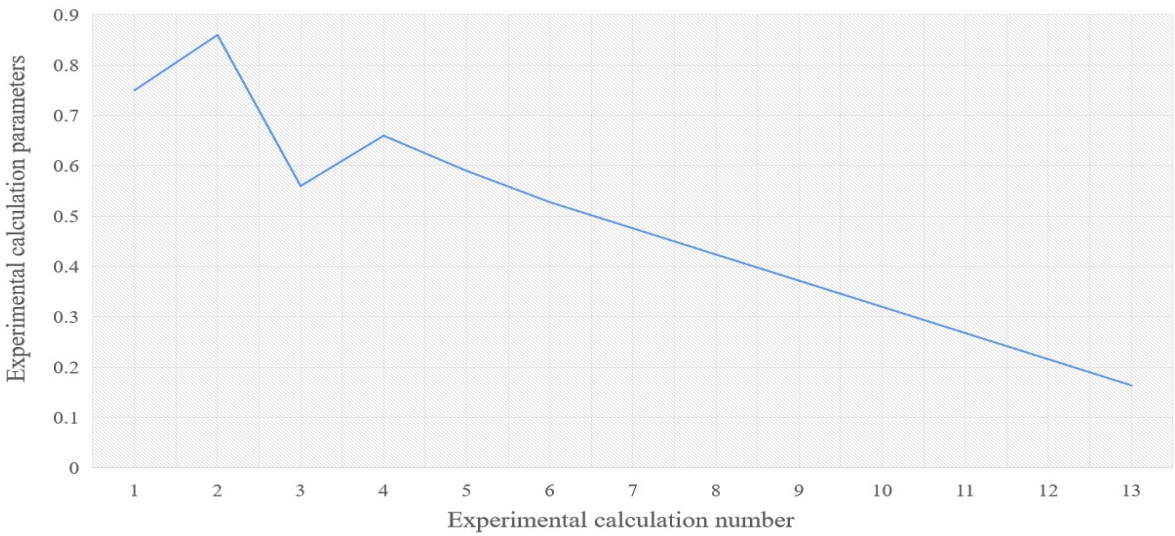

Fig. 2 Simulation analysis data of the final stage of missile

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The solution of the missile trajectory can be close to the actual trajectory curve. To solve the missile trajectory in the simulation trainer is to use the computer simulation technology. Using the system identification theory to solve the missile trajectory, the calculation amount is small and the real-time performance is strong, and the solved missile trajectory is basically consistent with the actual trajectory curve. The result identified by the system identification is based on good batch of input and output data, and the output residual sequence is required to have good statistical characteristics, and its confidence is ≥95%. Therefore, by simulating ballistic missiles with different ranges and different boosting stages, some basic characteristics of the position, velocity and acceleration changes of ballistic missiles in each stage can be analyzed. These results provide good guidance for the design and analysis of ballistic missile tracking methods. For example, the acceleration in the active phase changes sharply, the acceleration from the active phase to the free phase decreases instantaneously, and the acceleration in the reentry phase suddenly changes, which will cause the specific numerical value of the missile to become unstable and the parameters to change unnecessarily[7-8]. The ballistic missile with multi-stage boost is modeled and simulated, and the motion equations of the active stage, the free stage and the reentry stage with multi-stage boost are deduced, which clearly improves the calculation accuracy of the missile.

3. Propose a Solution to the Problem of Missile Trajectory Optimization.

3.1 Direct Method

This part becomes discrete transformation; Then we begin to solve NLP problem, so the direct method includes discrete transformation and nonlinear programming. Compared with the indirect method, the direct numerical method is used to directly optimize the performance index, which is more widely used and has many kinds.

3.2 Direct Shooting Method

Direct shooting method is the most commonly used form of direct method, and its most remarkable feature is that only the control variables are dispersed in time domain, and the state variables are obtained by explicit numerical integration method, so as to obtain the objective function and transform the optimal control problem into a nonlinear programming problem. It mainly discretizes the time-continuous optimal control problem, thus transforming the original problem into solving a nonlinear programming problem[9]. The specific discrete time is shown in the formula, and the corresponding control variables at discrete time nodes are used as design variables. The values of control variables between adjacent time nodes can be obtained by cubic spline interpolation. Thus, when the values of a group of design variables are known, the specific expression of control can be obtained by interpolation, and then the state variables can be obtained by integrating them into the state equation, and then the performance index function and constraint equation can be solved.

3.3 Proportional Guidance Method

Proportional guidance refers to a guidance method in which the rotational angular velocity of the missile's velocity vector has a certain proportion to the rotational angular velocity of its connecting line with the pursuit target during the missile's flight. It can adjust its own parameters to meet the changes of the other two methods. Therefore, compared with the other two methods, the proportional guidance method has great advantages.

3.4 Multiple Direct Shooting Method

The basic idea of direct shooting method and multiple shooting method is that the control variables are only dispersed and parameterized in the whole time interval, and the state variables are obtained by explicit numerical integration, so as to further obtain the performance index function, and the optimal control problem is converted into nonlinear programming, and the parameters to be obtained after the control variables are dispersed are determined by optimizing the performance index function.

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3.5 Orthogonal Collocation Method

Orthogonal Collocation Method, a kind of weighted residuals method, can be used to solve the initial and boundary value problems of linear and nonlinear ordinary differential equations and partial differential equations. This method is especially suitable for solving nonlinear problems. Compared with the traditional difference method, it has the advantages of high calculation accuracy and good stability. Orthogonal Collocation Method, a kind of weighted residuals method, can be used to solve the initial and boundary value problems of linear and nonlinear ordinary differential equations and partial differential equations. This method is especially suitable for solving nonlinear problems. Compared with the traditional difference method, it has the advantages of high calculation accuracy and good stability. It has a good response and feedback for the calculation of missile trajectory and precise guidance.

3.6 Sum of Parameter Optimization Methods

Structured mesh generation can be divided into algebraic method, conformal transformation method and numerical method for solving partial differential equations. The latter can be divided into three types: elliptical, parabolic and hyperbolic. The development of hydrodynamics can be calculated by using structured grid method, which not only depends on the development of computer technology and numerical calculation methods, but also largely depends on the development of grid generation technology. Only with the reliable and practical mesh generation technology that can be used for complex shapes, can all the functions of the flow field solution be realized. From a certain point of view, it is even more difficult to automatically generate an ideal grid distribution around a complex shape than to compile a three-dimensional flow field solution. Grid generation technology is one of the key technologies faced by CFD as an effective tool for aerodynamic engineering applications[10]. By integrating and modifying the optimization methods, we can use the current information background to calculate the trajectory of the missile, and we can get the data Fig. 3:

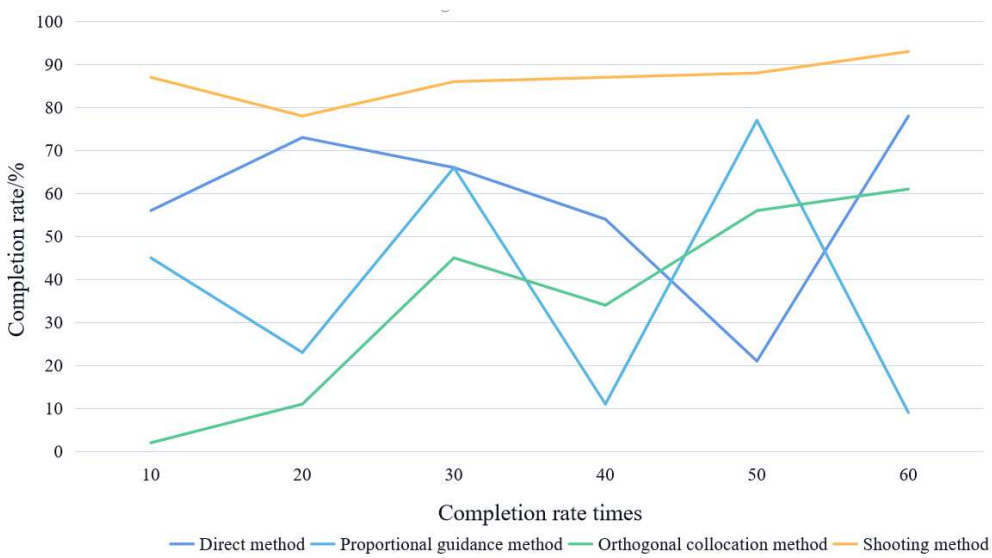

Fig. 3 Completion rate of four methods in missile test

As shown in Fig. 3: Compared with Delaunay method, the grid generation efficiency is lower and the grid quality is slightly worse. However, by improving the data structure and algorithm, as well as smoothing and optimizing the generated grid, the shortcomings of the above-mentioned front advancing method can be overcome. At present, some researchers have combined the above two methods to achieve the effect of learning from each other's strengths. Although the partition technology of structured grid and the generation technology of unstructured grid are quite mature at present, each of them has some inherent advantages and disadvantages, because it can be seen from

the Fig. that the completion rate of shooting method is impeccable in terms of completion efficiency and quality.

4. Conclusion

In this paper, the system identification theory is used to solve the missile trajectory, which has a small amount of calculation and strong real-time performance. The solved missile trajectory is basically consistent with the actual trajectory curve, and the flight trajectory of the surface-to-surface ballistic missile is studied. Through the research and theoretical derivation of the ballistic characteristics of surface-to-surface missiles, the theoretical basis is established. Then, the solution method which can effectively improve the missile strike accuracy and optimization efficiency is studied. Aiming at the missile multi-objective optimization model established in the research, the multi-objective optimization of the missile is transformed into a single-objective optimization problem by weighted sum method, and then it is transformed into a parameter optimization problem by direct shooting method. The ballistic missile with multi-stage boost is modeled and simulated, and the motion equations of active stage, free stage and reentry stage with multi-stage boost are derived. The process of trajectory extrapolation based on fourth-order Runge Kutta is given. In the experiment, the flight trajectory of ballistic missile with three-stage boost stage is simulated, and the law of velocity and acceleration changes and its influencing factors are analyzed. In the process of ballistic optimization, the convergence is slow and the optimization effect is not as good as that of medium-range and long-range. According to the characteristics of short-range ground-to-ground missile flight trajectory and the influence of ballistic parameters on flight trajectory, further research can be made. In view of the long flight time and poor maneuverability of medium-range and intercontinental ballistic missiles, guidance control can be added in the passive flight of the missile to make it maneuver, so as to improve the penetration ability and trajectory calculation ability of the missile. In the process of solving the multi-objective model, this paper only uses the weighted sum method to transform it, but does not study and compare various solutions of the multi-objective optimization problem, which will affect the expected effect of multi-objective model optimization. It is of great significance to study the motion characteristics and tracking of ballistic missiles in the future.

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