Online Command and Guidance Strategy Generation Method Based on Rolling Time Domain Control

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Abstract. In order to generate the command and guidance tactics path based on the current battlefield situation information in real time, a method of online generation of command and guidance strategy based on rolling time domain control is proposed. Firstly, the optimal control model of command and guidance strategy is established. Then the rolling time domain control method is applied to the command and guidance strategy generation model, and conducted a solution study. Finally, a simulation study was conducted on a PC, The simulation results show that the on – line command and guidance strategy generation method based on rolling time domain control is reasonable and effective, which is in line with the actual situation of air combat.

1. Introduction
Command and guidance strategy online generation refers to the series of tactical maneuvers that are made through a series of maneuvering instructions to effectively control the implementation of the air-to-air combat in order to achieve the purpose of making my aircraft superior to the enemy's tactical superiority.

At present, Shengxiang Zhang uses rolling time domain method to solve the trajectory planning problem [1]. Andong Liu Design and modeling of rolling time domain controller for time delay, packet loss and quantization problems in NCSs [2]. Zhaowang Fu used rolling time domain control method to model the decision-making of air combat maneuver [3]. Siliang Hua proposed RHC formation control method based on quadratic programming [4]. Shengxiang Zhang uses rolling time domain method to conduct deep research on the trajectory planning of small UAV [5]. Hong Chen and other methods using rolling time domain estimation of continuous stirred tank reactor temperature and concentration [6]. Literature [7] studied the rolling time domain in the three-volume system. In air combat, battlefield information is complex and changeable. In order to provide better command and guidance support for fighter planes, the change of dynamic environment information must be fully considered, and command and guidance tactical paths based on current situation information must be generated online and in real time. Because the rolling time domain control method can effectively solve the problem of online generation of command and guidance countermeasures, this paper uses this method to carry out research.

In this paper, a model of air combat command and guidance strategy generation for fighter aircraft is established, and the optimal command and guidance strategy for single aircraft is generated online by rolling time domain control, which effectively ensures the timeliness of command and guide strategy and effectively meets the command and guidance needs under complex battlefield environment.
2. Command and Guidance Strategy Generation Model

2.1. Problem Description

Command and guidance strategy generation problem can be abstracted as the optimal tactical path planning problem. In order to facilitate the computer processing, the dynamic use of discrete-time linear state space model:

\[ s_{k+1} = As_k + Bu_k \]

where \( u_k \) is the control vector of the aircraft and \( s_k \) is the state vector of the aircraft.

2.2. Command and Guidance Strategy to Generate Optimal Control Model

In this paper, the command and guidance strategy is modeled as the optimal control problem.

\[ J(x,u) = \int_0^{t_f} L(x,u,t)dt + \phi(x_f,t_f) \]

\[ s.t. x = f(x,u,t), x(t_0) = x_0 \]

\[ g(x,u,u,u) \leq 0 \]

\[ h(x_f) = 0 \]

Where \( J(x,u) \) is the performance index, \( L(x,u,t)dt \) includes the input cost and the price of the deviation between the state corresponding to each discrete moment and the target state, and \( \phi(x_f,t_f) \) is the final value of the terminal state corresponding to the terminal time. \( x = f(x,u,t), x(t_0) = x_0 \) is the system state equation; \( g(x,u,u,u) \leq 0 \) is the control constraint; \( h(x_f) = 0 \) is the time boundary condition.

The system state vectors denoted by \( \vec{X} = [X_F, X_T]^T \), \( X_F \) and \( X_T \) respectively represent the motion state vectors of my machine and the target machine in the inertial coordinate system.

Set \( X_F = [X_F, Y_F, V_{F\theta'}, V_{F\phi'}, h_F]^T \) that my machine's motion state, \( X_T = [X_T, Y_T, V_{T\theta'}, V_{T\phi'}, h_T]^T \) that the target machine's motion state. Among them, \( (X_F, Y_F) \) and \( (X_T, Y_T) \), respectively, for the position coordinates of my fighter and the target fighter. \( (V_{F\theta'}, V_{F\phi'}) \) and \( (V_{T\theta'}, V_{T\phi'}) \), respectively, for the speed components of my fighter and the target fighter, \( h_F \) and \( h_T \) respectively, for the height of my fighter and the target fighter.

Due to the long-range air combat situation, it can be approximated that the carrier and the target fighter in the same horizontal plane, that is \( h_F = h_T \), the motion of target state is \( X_T \), the target fighter's motion equation is expressed as:

\[
\begin{align*}
\dot{x}_T &= v_T \cdot \cos \chi_T \\
\dot{y}_T &= v_T \cdot \sin \chi_T \\
\dot{v}_T &= a_t
\end{align*}
\]
Among them, $\chi_i$ is the heading angle of target fighter; $v_i$ is the speed scalar of target fighter speed scalar; $a_i$ is the maneuvering acceleration of target fighter.

3. Online Command Guidance Strategy Based on Rolling Time Domain Control

3.1. RHC Tactics Command and Guidance Strategy Generation Model

Establish the optimal open-loop control solution model, as shown below:

$$J_k(u^*) = \int_{t_k}^{t_{k+1}} L(x,u,t)dt + V(x(t_k+T),t_{k+1}+T)$$

subject to

$$x = f(x,u,t), x(t_k) = x_k$$

$$g(x,u,u,u) \leq 0$$

$$h(x(t_k+T)) = 0$$

In the formula, $V(x(t_k+T),t_{k+1}+T)$ is a value function, $t_{k+1}$ is used to approximate the optimal price to the final state $x_f$.

The approximate indicator function.

$$\tilde{J}(u) = -\tilde{J}_s(u) + \omega J_s(u) + (1-\omega) J_s(u)$$

$$\tilde{J}_s(u) = \int_{t_k}^{t_{k+1}} E(t)dt + E(t_k + T) \frac{r(t_k + T) - r_f}{v_f(t_k + T)}$$

$$\tilde{J}_s(u) = \frac{r(t_k + T) - r_f}{v_f(t_k + T)}$$

$$\tilde{J}_s(u) = \int_{t_k}^{t_{k+1}} \chi_f(t)dt + \chi_f(t_k + T) \frac{r(t_k + T) - r_f}{v_f(t_k + T)}$$

(17) is the approximate function of the cumulative remaining time dominance value. (18) is the approximate function of the remaining system runtime. (19) is the approximate cumulative solution to the angle of maneuvering in the time domain.

3.2. Solution Strategy Based on Rolling Time Domain

First, Discrete time.

$$t_k = t_k^0 < t_k^1 < \cdots < t_k^N = t_k + T$$

Parameterized processing of the command and guidance control of the carrier.

$$u(t_k^i) = u_i, i = 0, \cdots, N$$

To further reduce the scale of the problem, order $t_k^i - t_k^{i-1} = \Delta t + i \Delta t$. The transformed nonlinear programming problem is to solve the following objective function.

$$\min \tilde{F}(u_0, \cdots u_{N-1}) = \sum_{i=0}^{N-1} L(x_i, u_i, t_k^i)(t_k^{i+1} - t_k^i) + V(x_f, t_k^N)$$

$x_i$ is the initial state corresponding to each discreted moment $t_k^i$. Finally, solve the NLP problem using the GPNOPS-SNOPT toolbox.
4. Simulation

In order to verify the validity of the model, the numerical simulation method is used to simulate the target non maneuverability and maneuverability. The simulation is carried out on a PC with a CPU of 3.60GHz and is solved by using the SNOPT software package in the MATLAB environment. Simulation initial conditions shown in Table 1:

| Parameter | $x(0) / \text{km}$ | $y(0) / \text{km}$ | $v(0) / (\text{m} \cdot \text{s}^{-1})$ | $a(0) / (\text{m} \cdot \text{s}^{-2})$ | $\omega(0) / (\text{rad})$ | $h(m)$ |
|-----------|-------------------|-------------------|------------------|------------------|------------------|--------|
| Enemy fighter | 80 | 65 | 300 | 0 | -100 | 0.8 | 3000 |
| My fighter | 0 | 0 | 300 | 0 | 30 | 0.2 | 3000 |

Figure 1. Maneuver trajectory without confrontation.

Figure 2. Maneuver trajectory in case of confrontation.
From Figure 1 and figure 3, we can see that when the target is not maneuvering, we can quickly find a superior tactical path to achieve the target attack conditions, and our command and guidance tactical advantage increases with the tactical maneuverability of our fighter. Figure 2 and Figure 4 can be seen that when the target fighter maneuver, my fighter using RHC-based command and guidance maneuver strategy can also generate an online advantage tactical path to achieve the target attack conditions. Although there is some fluctuation in the tactical advantage value of my fighter's command and guidance, the overall trend is upward. The simulation results show that the rolling time domain control method can generate the command and guidance countermeasures online whether in the case of confrontation or non-confrontation, which verifies the effectiveness of the method.

5. Conclusion
Based on the characteristics of air combat command and guidance, this paper studies online generation of single command and guidance strategy. Abstracts the command and guidance strategy generation problem as the optimal control problem, and sets up the command guidance strategy to generate the optimal control model. At last, a rolling time-domain control method is used to generate command guidance countermeasure online. Simulation results show that the online command and guidance strategy generation method based on rolling time domain control can adapt to the complex air battlefield environment, can effectively sense the battlefield environment and make correct responses,
generate the command and guidance strategy of fighter planes in the air combat process in real time, and provide a new method for command and guidance strategy generation.

6. References
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