Optimization of UAV Flight Control Algorithm and Flight Simulation in Two-dimension

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Abstract. Large-scale Unmanned Aerial Vehicle (UAV) groups flight simulation in two-dimensional planes is commonly applied to UAV cluster mission planning algorithm design. In this paper, an UAV control algorithm optimized for two-dimensional planes is designed. The tandem structure of closed loops, as well as the control laws of L1 and Total Energy Control System (TECS), are transplanted to an UAV model that is simplified to a moving particle of a two-dimensional space, and UAV flight simulation is performed based on the flight control algorithm. Compared with the traditional 3D space flight simulation, it can save hardware resources and improve the simulation efficiency. Compare with the flight simulation based on the geometric method, on the premise of maintaining the dynamics basis, the trajectory and dynamics curves are closer to the actual flight results in 3D space, and the dynamics data onto the entire flight can be recorded. It has been verified that 50 UAVs need only 0.8s to perform 100 square-area snake-like search simulation experiments, and the fitting degree of the UAV's flight curve to the three-dimensional space is greater than 80%. The two-dimensional plane flight control algorithm and flight simulation proposed in this paper provide a new simulation method for the design of UAV cluster mission planning algorithms, therefore can help promote the development of the subject.

1. Introduction
In modern wars, UAVs, as an important reconnaissance force, have been increasingly used by various countries. The UAV flight process is mainly divided into take-off, cruise and descent recovery (final guidance) stages. The main flight process is cruise at fixed altitude. Therefore, in the simulation experiments of the UAV task planning algorithm, the planned waypoints are often set on a two-dimensional plane. For many long-time flight simulations involving large number of UAVs, such as machine learning-based UAV mission planning algorithms, traditional 3D dynamic simulation is inefficient due to excessive computing power consumption, and the number of simulation nodes is limited by hardware resources; The path simulation based on geometric method lacks a dynamic basis, which results in a large difference between the simulation result and the actual trajectory, low reliability, and unable to perform dynamic data recording and analysis. Therefore, it is necessary to design UAV trajectory simulation method of a dynamic basis that can simulate the 3D space UAV dynamic trajectory on a 2D plane, can track and record the dynamic data, and only consume small amount of calculation and hardware resources.

This paper designs a fixed-wing UAV flight control algorithm optimized for 2D planes for flight simulation in mission planning. The track points are input in a two-dimensional plane with a certain
height. Based on the UAV adaptive control algorithm in three-dimensional space, the UAV flight control algorithm in two-dimensional space is designed to quickly and stably generating a flight trajectory that simulates the real environment, and record the kinetic data in flight process.

The structure of this paper is as follows: Section 2 introduces the algorithm background, that is, the problem of transplanting UAV flight control algorithm in three-dimensional space, normal L1 and tangential TECS (Total Energy Control System) flight control algorithm to two-dimensional environment.[3] The third section introduce the cascade closed-loop flight control algorithm of UAV in two-dimensional plane separately from the outer and inner loops. Section 4 uses the personal PC as the hardware foundation, and simulates the algorithm on the Python3.5.2 platform, and compares it with the geometric method and three-dimensional space flight dynamics simulation curves. Section 5 summarizes the advantages of the algorithm and its value of the development of UAV cluster task planning algorithms.

2. Background Description

The solution proposed in this paper is to design a two-dimensional plane UAV flight control algorithm. The L1 and TECS flight control algorithms in three-dimensional space are transplanted to a two-degree-of-freedom UAV model that is simplified to two-dimensional moving particles.

This section briefly analyses the UAV motions model in the two-dimensional space, then proposes the main problems and solutions.

2.1. Two-dimensional plane UAV motion model

In order to improve the efficiency of the UAV control in the two-dimensional plane and reduce the complexity of the control algorithm as much as possible, this paper first discusses the simplified model of the UAV. The simplified UAV dynamics model is the basis of the two-dimensional planar UAV control algorithm. It should meet the following three requirements[4]:

- Able to do two-degree-of-freedom motion in a two-dimensional plane;
- Able to transparent L1 and TECS adaptive control laws in a two-dimensional plane;
- Under the first two conditions, the model dynamic parameters are minimized.

In a two-dimensional coordinate plane, simplifying an UAV into a moving particle of a velocity direction is the limit of the simplification of a motion model that can be achieved. So the UAV body model assumes the following:

- The UAV is a particle, and its speed direction coincides with the direction of the UAV axis;
- UAV propulsion controls the thrust by adjusting the throttle;
- The resistance to the UAV is constant;
- UAV cruise altitude and desired airspeed are constant.

This model involves coordinate systems including cruise plane coordinate system \( S_r(x,y) \) and airflow coordinate system \( S_w(x_w,y_w) \), which are defined as follows:

- Cruise plane coordinate system \( S_r(x,y) \): The origin is selected at the position of the center of mass when the UAV starts cruising. In the horizontal plane, \( O_x \) points to the north direction and \( O_y \) points to the east direction;
- Airflow coordinates system \( S_w(x_w,y_w) \): The origin is at the center of mass of the UAV, the \( o_w x_w \) direction is consistent with the speed direction, and the \( o_w y_w \) direction and \( o_w x_w \) direction are at an angle of 90° clockwise. The general diagram are shown as figure 1.
Among them, the angle between the \( o_w x_w \)-axis of the air current coordinate system and the \( o_e x_e \)-axis of the cruise plane coordinate system is the azimuth of the track in a two-dimensional plane, which is denoted as \( \chi \). The UAV motion model can be described by the following equation:

\[
\begin{align*}
\dot{x}_w &= \dot{x}_{w,\text{obs}} + a_{w} \times dt \\
\dot{y}_w &= \dot{y}_{w,\text{obs}} + a_{w} \times dt
\end{align*}
\] (1)

Where \( \dot{x}_w, \dot{y}_w \) is the tangential and normal speed of the UAV at time \( t+1 \); \( \dot{x}_{w,\text{obs}}, \dot{y}_{w,\text{obs}} \) is the actual tangential and normal speed of the UAV at time \( t \); \( a_{w} \) is the tangential and normal acceleration of the UAV at time \( t \); \( dt \) is integral. The step size, the minimum time interval, depends on the frequency of the UAV status sensor.

By projecting the UAV speed in the air current coordinate system to the cruise plane coordinate system, we get the speed \( \dot{x}_e, \dot{y}_e \) of the UAV in the direction of cruise plane \( x \) and \( y \):

\[
\begin{align*}
\dot{x}_e &= \dot{x}_w \times \cos \chi - \dot{y}_w \times \sin \chi \\
\dot{y}_e &= -\dot{x}_w \times \sin \chi - \dot{y}_w \times \cos \chi
\end{align*}
\] (2)

2.2. Improvement plan

According to the definition of the UAV motion model in Section 2.2, the default UAV height will not change in the two-dimensional plane, which is an environmental constraint and therefore cannot be controlled. Think of the UAV as a moving mass, and it does not involve attitude angle and steering gear control. Based on the establishment of a two-dimensional plane UAV motion model, the research problem of this paper is transformed into a three-dimensional space UAV control algorithm being transplanted to a two-dimensional space simplified motion model. The control objects are the normal and tangential acceleration of the UAV, and the purpose is to achieve rapid tracking of the mission planning trajectory and airspeed.[5]

Similar to the effect of the lateral acceleration of the UAV in three-dimensional space[1], the normal acceleration of the UAV controls the yaw distance of the UAV so that the UAV approaches the desired track and is controlled by the L1 algorithm; the tangential acceleration controls the UAV Airspeed, controlled by TECS algorithm.

In summary, the design steps of the two-dimensional planar UAV control algorithm can be summarized as:

- Decompose the UAV control algorithm into outer and inner loop controllers, and decompose the outer loop controller into L1 controller with normal acceleration control and TECS controller with tangential acceleration control;
- Design TECS and L1 control algorithms for two-dimensional planes;
- Design the inner loop PID control algorithm;
- Debug the outer loop and inner loop control parameters to optimize the control effect;
- Simulate outer loop and inner loop control effects.

3. UAV flight control algorithm based on L1 and TECS

In UAV mission planning algorithms, UAVs are often reduced to two-degree-of-freedom aircraft on a two-dimensional plane. For many long-time flight simulations involving a large number of UAVs, such as machine learning-based UAV mission planning algorithms, traditional 3D dynamic simulation is inefficient due to excessive computing power consumption, and the number of simulation nodes is limited by hardware resources; The path simulation based on geometric method lacks a dynamic basis, which results in a large difference between the simulation result and the actual trajectory, low reliability, and unable to perform dynamic data recording and analysis.

3.1. Cascade closed-loop control strategy

The structure of the UAV control system is shown as figure 2.

![Figure 2. Schematic diagram of two-dimensional planar UAV cascade control](image)

According to the function of the control loop, the inner loop is the acceleration control system of the UAV, which is used to control the tracking of the UAV's acceleration to the expected acceleration. The outer loop is a trajectory control loop that calculates the expected acceleration, controls the speed and yaw distance of the UAV, and enables the UAV to fly along the predetermined route and airspeed at the desired speed.

According to the control channel decomposition, the control system can be divided into tangential control system and normal control system. The tangential control system controls the acceleration of the UAV along the speed direction, using the TECS control algorithm; the normal control system controls the acceleration of the UAV along the vertical speed direction, and uses the L1 control algorithm.

3.2. Lateral acceleration algorithm based on L1 adaptive control

The L1 control algorithm of the UAV in the two-dimensional plane also makes the motion of the UAV close to the desired trajectory in the two-dimensional plane. The application scenario is as follows:

- In a two-dimensional plane, the position \( P(x_p, y_p) \) and speed \( V(v_x, v_y) \) of the UAV at a certain moment are known;
- The desired track segment \( i \) is a straight line segment from the initial waypoint \( A (x_{i}^{'}, y_{i}^{'}) \) to the end waypoint \( B (x_{i}^{'}, y_{i}^{'}) \). If the UAV reaches the ending waypoint at this time, and the ending waypoint is not at the end of the waypoint list, then the ending waypoint is set as the initial waypoint at the next time, and the next waypoint in the waypoint list is the ending waypoint. If the end waypoint is not reached at that time, the initial waypoint and the end waypoint at the next time are unchanged;
The L1 control law calculates the expected normal acceleration $a_{l_{exp}}$ pointing to the desired track perpendicular to the speed direction. According to the position relationship between the position of the UAV and the desired track, the angle $\eta$ between the speed direction and the virtual waypoint is calculated in three cases, so that the UAV can approach the endpoint of the desired track segment as soon as possible when it is away from the desired track segment. In either case, the L1 length is always determined by the product of speed and natural frequency:

$$L_1 = V \cdot L_{ratio}$$  \hspace{1cm} (3)

Among them, $L_1$ is the distance from the current position to the virtual waypoint, and $L_{ratio}$ is the natural frequency, which represents the ratio of the expected airspeed to $L_1$.

**Scenario 1.** From the UAV position to the desired flight path segment, foot $C(x_c, y_c)$ is located outside the desired flight path segment and is close to the initial waypoint $A(x_a, y_a)$, as shown in the figure 3. $O(x_o, y_o)$ is the virtual turning circle centre.

![Figure 3. Schematic diagram of scenario 1](image)

That is, when $\cos \angle PAB < 0$, the virtual waypoint is set as the initial waypoint. The size of L1 is independent of the relative initial waypoint position, and $\eta$ is the angle from the UAV speed to $PA$. The calculation formula for $\eta$ is as follows:

$$\cos \eta = \frac{V \cdot PA}{|V| \cdot |PA|}$$

$$R = \frac{L_1}{2 \sin \eta} = \frac{L_1}{2 \sqrt{1 - \cos^2 \eta}}$$  \hspace{1cm} (4)

Therefore, the expected lateral acceleration $a_{l_{exp}}$ is calculated as:

$$a_{l_{exp}} = \frac{V^2}{R} = \frac{V^2}{L_1} \cdot \frac{2 \sqrt{1 - \cos^2 \eta}}{2 \sin \eta}$$  \hspace{1cm} (5)

With equations 5 and 6, the expected lateral acceleration is expressed as:

$$a_{l_{exp}} = \frac{2V}{L_{ratio}} \sqrt{1 - \left(\frac{V \cdot PA}{|V| \cdot |PA|}\right)^2}$$  \hspace{1cm} (6)

**Scenario 2.** UAV positions to the desired track segment, foot $C(x_c, y_c)$ is located outside the desired track segment, and is close to the ending waypoint $B(x_b, y_b)$, as shown in the figure 4:

![Figure 4. Schematic diagram of scenario 2 (left) and Schematic diagram of scenario 3 (right)](image)
When \( \cos \angle PBA < 0 \), set the ending waypoint as a virtual waypoint. As in the first case, although the length of \( L_1 \) is proportional to the speed of the UAV, the selection of the virtual waypoint has nothing to do with the size of \( L_1 \) until the end waypoint is reached.

\[
\cos \eta = \frac{\vec{V} \cdot \vec{PB}}{|\vec{V}| \cdot |\vec{PB}|} \quad (8)
\]

\[
a_t^{\text{exp}} = \frac{2V}{L_1} \sqrt{1 - \left(\frac{\vec{V} \cdot \vec{PB}}{|\vec{V}| \cdot |\vec{PB}|}\right)^2} \quad (9)
\]

**Scenario 3.** From UAV position to desired track segment, foot \( C(x_c, y_c) \) is located in the desired track segment, as shown in the figure 4:

At this time, \( \cos \angle PAB > 0 \) and \( \cos \angle PBA > 0 \) are standard L1 algorithm scenarios, and the virtual waypoint is located on track segment \( AB \), and the distance to \( P_e \) is \( L_1 \).

Let \( \eta \) be the angle between \( \vec{V} \) and \( \vec{AB} \), and \( \eta_1 \) be the angle between \( \vec{PC} \) and \( L_1 \), then the angle \( \eta \) can be expressed as:

\[
\eta = \arccos \left(\frac{\vec{V} \cdot \vec{AB}}{|\vec{V}| \cdot |\vec{AB}|}\right) \quad \eta_1 = \arcsin \left(\frac{|\vec{PC}|}{L_1}\right) \quad (10)
\]

\[
\eta = \frac{\pi}{2} + \eta_1 - \eta_2 \quad (11)
\]

\[
\sin \eta = -\cos (\eta_1 - \eta_2) \quad (12)
\]

Therefore, the virtual turning radius formula is:

\[
R = \frac{L_1}{2 \sin \eta} = \frac{V \cdot L_1 \text{ratio}}{2 \sin \eta} = -\frac{V \cdot L_1 \text{ratio}}{2 \cos (\eta_1 - \eta_2)} \quad (13)
\]

The formula of the normal acceleration of the UAV is:

\[
a_t^{\text{exp}} = \frac{V^2}{R} = \frac{V^2}{L_1} \frac{2 \sin \eta}{2 \sin \eta} = \frac{-2V}{L_1} \text{ratio} \cos (\eta_1 - \eta_2) \quad (14)
\]

The empirical parameter \( K_{\text{lat}} \) is introduced here to adjust the problem that the normal acceleration of the UAV in the two-dimensional plane is too large and serious overshoot. Therefore, the expected normal acceleration \( a_t^{\text{exp}} \) after optimization is:

\[
a_t^{\text{exp}} = a_t^{\text{exp}} \cdot K_{\text{lat}} \quad (15)
\]

The normal acceleration direction is perpendicular to the speed and points to the track segment. In summary, the expected normal acceleration of the UAV in the two-dimensional plane can be obtained.

3.3. Algorithm for Tangential Acceleration of Outer Ring Based on TECS Control

TECS control the size of the UAV’s throttle to change the output power of the UAV’s engine, and controls the UAV’s elevator to change the power ratio of the UAV’s potential energy and kinetic energy to maintain or adjust the UAV’s flying height[6]. In a two-dimensional plane, the height of the UAV does not need to be adjusted, so the potential energy of the UAV is constant. Based on the most simplified principle, the UAV altitude potential energy is set to zero. The TECS algorithm for a two-dimensional plane can change the output power of the UAV by controlling the throttle valve without changing the potential energy, so as to track the desired speed. The application scenario is described as follows:

- The UAV’s flight speed is \( V_{\text{set}} \) at a certain moment, and the expected airspeed given by the mission plan is \( V_{\text{set}}^{\text{Ut}} \).
- Limited by the performance of the UAV engine, the change rate of the total specific energy of the UAV is constrained within the interval \([\text{ST}E_{\text{rate}}^{\text{min}}, \text{ST}E_{\text{rate}}^{\text{max}}]\), where \( \text{ST}E_{\text{rate}}^{\text{min}} < 0 < \text{ST}E_{\text{rate}}^{\text{max}} \).
Integrate UAV airspeed and desired airspeed, and calculate the expected throttle opening rate \( \text{throttle}_e \) of the UAV under the constraints of the total specific energy change rate and the controllable change interval of the throttle valve.

First, the expected airspeed change rate \( \text{TAS}_{\text{rate}} \) is the airspeed error at that moment, that is, the ratio of the expected airspeed to the actual airspeed difference and the time interval \( \Delta T \). Introduce the empirical proportional parameter \( K_e \) to adjust the change rate to avoid the failure of the speed control due to the expected change rate.

\[
\text{TAS}_{\text{rate}} = (\text{TAS}_{\text{act}} - \text{TAS}_{\text{ref}}) \cdot \Delta T^{-1} \cdot K_e
\]

(16)

From the specific energy calculation formula, the actual total specific energy \( \text{STE}_{\text{act}} \) and the expected total specific energy \( \text{STE}_{\text{ref}} \), and the total specific energy error \( \text{STE}_{\text{error}} \) can be obtained:

\[
\text{STE}_{\text{error}} = \text{STE}_{\text{act}} - \text{STE}_{\text{ref}} = \frac{1}{2} (\text{TAS}_{\text{act}}^2 - \text{TAS}_{\text{ref}}^2)
\]

(17)

The expected total specific energy change rate \( \text{STE}_{\text{rate}} \) is the expected change rate of the total specific energy obtained by multiplying the specific energy magnitude and the desired speed change rate at that moment.

\[
\text{STE}_{\text{rate}} = \text{TAS}_{\text{rate}} \times \text{TAS}_{\text{rate}}
\]

(18)

When the airspeed error rises, the expected airspeed change rate rises accordingly, which may exceed the UAV's engine controls range. Therefore, according to the actual control ability of the UAV, the calculation formula of \( \text{STE}_{\text{rate}} \) is as follows:

\[
\text{STE}_{\text{rate}} = \begin{cases} 
\text{STE}_{\text{rate}}_{\text{max}} > \text{STE}_{\text{rate}}_{\text{ref}} > \text{STE}_{\text{rate}}_{\text{min}} \\
\text{STE}_{\text{rate}}_{\text{max}} > \text{STE}_{\text{rate}} > \text{STE}_{\text{rate}}_{\text{min}} \\
\text{STE}_{\text{rate}}_{\text{max}} > \text{STE}_{\text{rate}}_{\text{max}} > \text{STE}_{\text{rate}}_{\text{ref}}
\end{cases}
\]

(19)

From the principle of UAV dynamics, it is expected that the total specific energy change rate is linearly related to the throttle opening rate, so the theoretical throttle opening rate \( \text{throttle}_t \) can be calculated. The reference throttle value of the UAV is \( \text{throttle}_{\text{const}} \). When the expected total specific energy change rate is greater than 0, the total specific energy of the UAV increases, and the throttle opening rate is directly proportional to the maximum opening rate \( \text{throttle}_{\text{max}} \). In contrast, when the expected total specific energy change rate is less than 0, the total specific energy of the UAV decreases, and the throttle opening rate are proportional to the minimum opening rate \( \text{throttle}_{\text{min}} \). Calculate as follows:

\[
\text{throttle}_e = \begin{cases} 
\text{throttle}_{\text{const}} + \frac{\text{STE}_{\text{rate}}_{\text{ref}} - \text{throttle}_{\text{max}}}{\text{STE}_{\text{rate}}_{\text{max}}} \cdot \text{STE}_{\text{rate}}_{\text{ref}} > 0 \\
\text{throttle}_{\text{const}} + \frac{\text{STE}_{\text{rate}}_{\text{ref}} - \text{throttle}_{\text{min}}}{\text{STE}_{\text{rate}}_{\text{min}}} \cdot \text{STE}_{\text{rate}}_{\text{ref}} < 0
\end{cases}
\]

(20)

In this case, the inner loop PID control algorithm for the tangential acceleration of the UAV can be designed by the specific energy error \( \text{STE}_{\text{error}} \), the throttle opening rate \( \text{throttle}_e \), and the expected total energy change rate \( \text{STE}_{\text{rate}} \) of the UAV.

3.4. Inner loop PID control algorithm

The UAV in the two-dimensional plane does not have the rudder surface control structure nor the attitude angles control capability. Therefore, the desired acceleration command \( \dot{a}_i \) and throttle opening rate \( \text{throttle}_e \) given by the outer ring controller of the inner ring controller are the control targets. Tangent two parts, through the PID controller to simulate the operation process of the inner loop controller in three-dimensional space.

The normal control law of the inner loop of the UAV is:

\[
\dot{a}_i = K_i \cdot \Delta a_i + K_p \cdot \int \Delta a_i \, dt + K_d \cdot a_i
\]

(21)
Among them, $\Delta a_i$ is the difference between the expected tangential acceleration and the actual tangential acceleration of the UAV at this moment, and $K^p_i$, $K^i_i$, and $K^d_i$ are the coefficients of the proportional link, the integral link, and the differential link.

The tangential control law of the inner loop of the UAV is:

$$\text{throttle}_{\text{true}} = \text{throttle}_{\text{true}} + \left( \text{STE}_{\text{error}} + \text{STError}_{\text{error}} \times K^p_i \right) \times K^i_i + K^d_i \times \int \text{STError}_{\text{error}} dt$$  \hspace{1cm} (22)

Among them, $\text{TASrate}_{\text{error}}$ is the difference between the expected airspeed change rate and the actual airspeed change rate at this moment, and $K^p_i$, $K^i_i$, and $K^d_i$ are the coefficients of proportional link, integral link, and differential link. Because the tangential acceleration of the UAV is proportional to the throttle opening rate, the actual tangential acceleration of the UAV at this time is:

$$a_{\text{true}} = K_{\text{acct}} \times \text{throttle}_{\text{true}}$$  \hspace{1cm} (23)

$K_{\text{acct}}$ is the tangential acceleration proportionality factor.

4. Generate trajectory and simulation calculation of dynamic parameters

In this paper, python3.5 is selected as the simulation platform. Using a two-dimensional plane flight controls algorithm, given a serpentine search waypoint sequence, patrol at a constant speed of 30m/s and a fixed height of 50m relative to the ground. The two-dimensional simulation trajectory, traditional calculation path based on the Dobbins curve and the flight path of the UAV dynamics simulation with the same waypoint in 3D space obtained is as figure 5:

![Figure 5](image_url)

**Figure 5.** Three-dimensional flight simulation trajectory of a fixed-wing UAV (previous page);
Trajectory simulation based on two-dimensional plane control algorithm (left) and Trajectory Simulation Based on Geometric Algorithm (right)

It can be seen that the two-dimensional simulation trajectory can simulate the track characteristics of the UAV slightly overshooting after reaching the waypoint, which is better than the Dubins curve track. The clue-aware trajectory similarity (CATS) algorithm is used to calculate the similarity with the 3D simulation trajectory[7]:

...
The approximation of the two-dimensional trajectory simulation curve is 0.83. The similarity is greater than 80%, indicating that the two-dimensional trajectory simulation is basically consistent with the three-dimensional trajectory simulation.

The normal and tangential speed curves of the two-dimensional plane UAV flight control algorithm, and the comparison diagram of the UAV speed curve in three-dimensional space are as figure 6 and figure 7.

![Figure 6. Three-dimensional space velocity curve](image)

![Figure 7. Two-dimensional space tangential velocity curve (left) and normal velocity curve (right)](image)

The tangential velocity in 2D simulation is basically consistent with the tangential velocity curve in 3D space simulation. When changing the direction of flight speed, the UAV's normal speed changes drastically, but it can converge to the 3D simulation value.

The tangential acceleration and normal acceleration curves of the two-dimensional simulation UAV are as figure 8:

![Figure 8. Two-dimensional space tangential acceleration curve (left) and normal acceleration curve (right)](image)

Fifty UAV serpentine formation searches flights took a total of 0.8s to calculate on a personal computer. The computing power of a three-dimensional dynamic simulation personal computer for the same scenario cannot be supported. Compared with the simulation trajectory obtained by the Dubins curve, it improves the approximation of the flight trajectory of a real UAV, and can output the dynamic parameters of a single UAV at any time.
5. Conclusion
This paper studies an UAV control algorithm optimized for two-dimensional planes. The core idea is to borrow the mature outer-loop control algorithm in three-dimensional space, that is, the TECS control law of the pitch channel and the L1 control law of the yaw and roll channels, and transplant it to a dynamic model that is simplified to a two-degree-of-freedom particle in the two-dimensional plane.

In this way, it can simulate similar motion trajectories and changes in dynamic parameters in three-dimensional space, and greatly reduce the computing power requirements of three-dimensional space dynamics simulation. Especially in the simulation of mission planning at the UAV cluster level, it can greatly save hardware resources and time costs. For simulation experiments that require a large number of UAVs for a long time and multiple flights, such as machine learning UAV mission planning algorithm design a large amount of simulation training is required. This algorithm can solve the problems of traditional path planning simulations such as the lack of dynamic basis in the Dubins curve and the low credibility of the planned path, making dynamic simulation under this kind of problem possible.

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