## Research on Dynamic Obstacle Avoidance Path Planning Strategy of UAV

### Abstract
In order to make the Unmanned Aerial Vehicle (UAV) avoid moving obstacles during operation, improve the survivability of the UAV in low-altitude dynamic and complex airspace, and ensure the safe operation of the UAV, a dynamic obstacle avoidance path planning strategy for UAV is proposed. When the UAV detects a moving obstacle, the UAV motion model is established considering the moving speed, moving direction and UAV turning radius of the UAV and the obstacle. Under the constraints of keeping the minimum safe distance between the UAV and moving obstacles as the premise, by changing the turning radius, changing the UAV heading, solving the UAV minimum deviation distance, reducing the UAV obstacle avoidance space, so that the obstacle avoidance effect of the UAV can be optimized. The simulation results show that the calculated minimum deviation distance is about 35% smaller than the maximum deviation distance within the changing range of turning radius. Changing the turning radius of the UAV can reduce the obstacle avoidance space of the UAV and improve the utilization of airspace resources. Using this model, the optimal dynamic obstacle avoidance path of the UAV can be solved.

### Keywords—UAV, safe operation, deviation distance, dynamic obstacle avoidance

### I. INTRODUCTION
In recent years, the research and application of Unmanned Aerial Vehicle (UAV) has shown a momentum of rapid development [1]. The Civil Aviation Administration of China (CAAC) Development Statistics Bulletin pointed out that by the end of 2020, there were about 558,000 registered users of drone owners in the industry, including about 498,000 individual users and about 60,000 users of enterprises, institutions, and legal entities. UAVs are widely used in logistics and distribution, image shooting, power inspection, emergency and disaster relief, crop spraying and other fields because of their low cost of use, mass production, and ability to accurately complete point-to-point tasks.

However, with the increase in the number of drones, a large number of UAVs will enter the low-altitude airspace, and the high-density UAV traffic flow increases the probability of UAV collisions in the air, which brings risks and challenge to UAV traffic management [2]. In the complex low-altitude airspace environment, the operation of UAVs is seriously threatened by moving obstacles such as birds and other aircraft. The ability of UAVs to effectively avoid moving obstacles has become the key to ensuring safe and orderly flight. UAV conflict resolution is an effective way to avoid moving obstacles, and the perception and avoidance function of UAVs is also one of the core technologies to ensure the operation safety of UAVs [3]. Aiming at the problem of UAV dynamic obstacle avoidance, some scholars proposed a UAV dynamic obstacle avoidance algorithm with improved artificial potential field, which solved the problem that the algorithm is prone to falling into local optimum and existing jitter, and achieved good results when avoiding dynamic obstacles. Better results [4-7]. Some researchers use heuristic algorithms to solve the problem of UAV dynamic obstacle avoidance. Common intelligent algorithms include genetic algorithm [8], particle swarm optimization [9], ant colony algorithm [10], etc. and other improved algorithms [11,12]. References [13-14] considered the UAV turning radius when studying the dynamic obstacle avoidance problem, which is more in line with the actual operation state of the UAV. Reference [15] introduced the theory of deep reinforcement learning into the decision-making process of UAV autonomous collision avoidance to realize the choice of UAV collision avoidance action in the dense dynamic obstacle environment.

The above research focuses on the UAV avoiding obstacles but does not consider the distance that the UAV deviates from the original path after changing the course to avoid obstacles. In a complex low-altitude airspace environment, the greater the deviation from the original path, the easier it is to hit static obstacles, such as buildings, and it will also increase the difficulty of the UAV returning to the original path. In this paper, the motion state of UAV and obstacles is considered, combined with the law of UAV motion, considering the variation range of UAV's turning radius. With the goal of minimizing the deviation from the original path, we propose a dynamic obstacle avoidance method for UAVs.

### II. DESCRIPTION OF UAV OPERATION

#### A. UAV Detects Obstacle
Other moving obstacles should be considered to invade the path of the UAV. Obstacles to movement can be other UFOs such as UAVs and birds. When the UAV is operating in the low-altitude airspace according to the planned path, it suddenly encounters other flying objects invading the operation path. Under the condition of "detection-perception-obstacle avoidance", when the UFO enters the detection range of the UAV, the UAV has operation risks. When the UAV detects the flight conflict, it should react quickly and change the local path to avoid the moving flying object, so as to achieve the purpose of safe operation. Obstacles detected by UAV are shown in figure 1:

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When the distance between the obstacle and the UAV is \(d\), the UAV can detect and sense the obstacle.

On the premise that there is a safe distance between UAVs and according to the movement rules of UAVs, a model of UAVs changing local paths to avoid moving obstacles is established, which provides theoretical support for UAVs to avoid dynamic obstacles.

**B. Deviation Distance of UAV.**

The UAV that changes course will deviate from its original path. On the one hand, due to the complexity of low-altitude airspace, for example, in the densely built urban environment, some ground buildings also pose a threat to the operation of UAVs. The greater the distance from the original path, the greater the threat from other static obstacles such as ground buildings. As shown in figure 2, the deviation distance \(L\) is the maximum distance from the original path in the whole process of the UAV avoiding the dynamic opening obstacles and returning to the original path.

\[
\begin{align*}
CD &= \frac{d \sin \theta_1}{\sin \theta_2} \\
AD &= d \cos \theta_1 - \frac{d \sin \theta_1}{\tan \theta_2}
\end{align*}
\]

**III. UAV DYNAMIC OBSTACLE AVOIDANCE MODEL**

**A. UAV Operating Status**

When the UAV runs along the planned path, it detects other moving obstacles (such as other running UAVs). On the premise of obtaining the orientation and motion state of the obstacle, the UAV actively changes the path to avoid the obstacle to reduce the risk of conflict. The schematic diagram of the model of the collision between the UAV and the dynamic obstacle is shown in figure 3:

The running UAV in the figure 3 is located at point A and runs along the planned path AB. When the distance between the obstacle and the UAV is the detection distance \(d\) of the UAV, the UAV perceives the motion state of the obstacle. The obstacle in motion is located at point C, runs in the direction of CD, and has a tendency to intrude into the UAV's path, possibly colliding with the UAV at point D. The angle between the UAV and the obstacle and the UAV path is \(\theta_1\), and the angle between the moving direction of the obstacle and the UAV path is \(\theta_2\). We can get the length of CD and AD from equation (1):

**B. UAV Turning Radius Range**

In this case, it is assumed that the motion state of the obstacle remains unchanged, and the UAV needs to actively change the path to avoid the obstacle. To avoid obstacles, the UAV needs to change its motion state to generate a safe path that can avoid obstacles. In order to meet the movement law of the UAV and be closer to the actual operation of the UAV, the UAV starts to make a circular motion at point A, and the running trajectory is an arc. The trajectory of the UAV is shown in figure 4:
Fig. 4. UAV Operation trajectory.

The green dotted line in the figure 4 is the new path generated by the UAV for obstacle avoidance, the orange line is the line parallel to the CD, and the distance from the CD is \( l \), and \( l \) is the length of the UAV’s minimum safe distance. The larger the turning radius \( R \) of the UAV in the figure 4, the smaller the distance between the UAV and the CD when the UAV is running. In order to ensure the safe operation of the drone, the distance between the UAV and the obstacle must be greater than the minimum safe distance.

At any point in the space to the left of the orange line, the distance from any point on the CD is greater than the minimum safe distance \( l \) of the drone. In the critical state, the new trajectory of the UAV is tangent to the orange line, and the turning radius of the drone reaches the maximum value at this time. If the maximum value is exceeded, the UAV will run to the right of the orange line, and the distance between the drone and the obstacle may be smaller than the minimum safe distance, threatening the safety of the UAV. According to the geometric principle, the maximum turning radius \( R_{\text{max}} \) of the UAV can be expressed as:

\[
R_{\text{max}} = \frac{d \cos \theta_1 - d \sin \theta_1 \tan \theta_2}{\tan \theta_2} \quad (2)
\]

In order to ensure that the UAV operates in a safe environment, the UAV turning radius must be less than or equal to the maximum turning radius. The minimum turning radius \( R_{\text{min}} \) of the UAV is related to its own performance and is generally a fixed value. In the model, the value range of the UAV turning radius \( R \) is:

\[
R_{\text{min}} \leq R \leq R_{\text{max}} \quad (3)
\]

C. UAV Deflection Time

After the UAV changes its flight path, it deflects within a certain time range. When there is no risk of collision between the obstacle and the UAV, the UAV returns to the original path according to its own motion law, so as to achieve the optimal effect of dynamic obstacle avoidance and maintaining the original path. When the obstacle moves from point C to point D, since the obstacle will continue to move forward, the drone will not collide with the obstacle when it returns to the original path. The time for the obstacle to move from point C to point D is the deflection time of the UAV. It can be represented by the equation (4):

\[
\begin{align*}
    t &= \frac{d \sin \theta_1}{V_1 \sin \theta_2} \\
    \varphi &= \frac{V_1 d \sin \theta_1}{R V_2 \sin \theta_2}
\end{align*} \quad (4)
\]

Where \( t \) is the deflection time of the UAV, \( V_1 \) is the deflection speed of the UAV, \( V_2 \) is the movement speed of the obstacle, \( \varphi \) is the deflection angle of the UAV after the deflection is completed.

D. The Equation of Deviation Distance

When the obstacle moves to point D and does not collide with the drone, the UAV completes the deflection process. But at this time, the drone is not in the optimal position in space. In addition to the original path, the UAV will also be affected by static obstacles such as buildings, and the greater the deviation distance from the original path, the greater the risk of UAV operation. In addition, the total length of the path from the UAV to the target point also increases, and the deviation from the original planned path reduces the operating efficiency of the UAV. The greater the distance the UAV deviates from the original path, the worse the UAV dynamic obstacle avoidance effect is.

After the UAV completes the deflection process, in order to optimize the operation performance of the UAV, it needs to return to the original path. In order to meet the motion law of the UAV, the UAV still performs circular motion. According to the deflection angle of the UAV, it is divided into the following situations:

1) \( \varphi < 90^\circ \):

When the UAV deflection angle \( \varphi \) is an acute angle, as shown in figure 5.

\[
L = (R + r)(1 - \cos \varphi) \quad (5)
\]

Where \( r \) is the deflection radius of the UAV’s return path.

2) \( 90^\circ < \varphi < 180^\circ \):

When the UAV deflection angle \( \varphi \) is an obtuse angle, as shown in figure 6.
Fig. 6. UAV motion state \((90°<\phi<180°)\).

The deviation distance \(L\) can be expressed as:

\[
L = R(1 - \cos \phi) + r(1 + \cos \phi)
\]

(6)

3) \(\phi > 180°\)

When the UAV deflection angle \(\phi\) exceeds 180°, as shown in Figure 7.

![Diagram](image)

Fig. 7. UAV motion state \((\phi>180°)\).

The size of the UAV deviation distance \(L\) is \(2R\).

**E. Objective Function**

The UAV deviation distance \(L\) is related to the UAV deflection angle \(\phi\). Summarizing the above three situations, the functional relationship expression of the UAV deflection distance is as follows:

\[
L = \begin{cases} 
(R + r)(1 - \cos \phi), & 0 < \phi \leq \frac{\pi}{2} \\
R(1 - \cos \phi) + r(1 + \cos \phi), & \frac{\pi}{2} < \phi \leq \pi \\
2R, & \phi > \pi
\end{cases}
\]

(7)

In order to optimize the deflection effect of the UAV, the deviation distance should be minimized. The UAV return path deflection radius \(r\) in equation (7) is changed to the UAV minimum turning radius \(R_{\text{min}}\) which can reduce the UAV deviation distance. After the change the expression of the UAV deviation distance \(L\) is:

\[
L = \begin{cases} 
(R + R_{\text{min}})(1 - \cos \phi), & 0 < \phi \leq \frac{\pi}{2} \\
R(1 - \cos \phi) + R_{\text{min}}(1 + \cos \phi), & \frac{\pi}{2} < \phi \leq \pi \\
2R, & \phi > \pi
\end{cases}
\]

(8)

It can be seen from equation (4) that the UAV deflection angle is related to the UAV speed, the obstacle speed and the UAV deflection radius. Combined with equation (4) and equation (8), the value of the deflection radius of the UAV determines the deviation distance of the UAV. In this model, in order to ensure that the UAV avoids obstacles safely, the UAV deflection radius has a maximum value. Selecting the appropriate UAV deflection radius to minimize the deviation distance and optimize the UAV obstacle avoidance effect is the key issue.

**IV. SIMULATION ANALYSIS**

Set the simulation parameters of the UAV and the model as shown in table I.

| \(V_1(\text{m/s})\) | \(V_2(\text{m/s})\) | \(R_{\text{min}}(\text{m})\) | \(\theta_1(\text{°})\) | \(\theta_2(\text{°})\) | \(d(\text{m})\) | \(l(\text{m})\) |
|----------------|----------------|----------------|---------------|---------------|------|------|
| 20             | 15             | 25             | 33°           | 63°           | 100  | 20   |

According to equation (2), referring to the relevant parameters in table I, it can be calculated that the maximum turning radius of the UAV is 54.94 m. According to the UAV deflection distance expression in equation (8), the UAV deflection radius is between the maximum value and the minimum value, and the function image of the deviation distance change is drawn as shown in figure 8.

![Graph](image)

Fig. 8. Deflection distance variation.

It can be seen from the figure 7 that the deviation distance first increases and then decreases with the increase of deflection radius. When the deflection radius of the UAV is 25 m, the deflection distance is the smallest, which is 50 m, It is about 35% less than the maximum value.

**V. CONCLUSION**

This paper presents a method for UAVs to avoid dynamic obstacles. Based on the premise of "detection-perception-obstacle avoidance", according to the movement law of the UAV, and under the premise of meeting the minimum safe distance, a solution model for the maximum deflection radius of the UAV is established. Then according to the UAV deflection time and deflection path, the UAV deviation
distance model is established. Under the premise of conforming to the law of UAV motion, the model can solve the minimum deviation distance of UAV, and make the UAV avoid the optimal path of dynamic obstacle. The UAV path also has the characteristics of smoothness, which can provide theoretical reference value for UAV dynamic obstacle avoidance.

In this paper, the dynamic obstacle avoidance path of UAV under the uncertainty of UAV deflection radius is studied. Further research can be done to solve the minimum deflection distance when more factors such as detection distance, UAV speed, minimum safe distance and included angle are uncertain.

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