Four-Rotor UAV Safe Landing Risk Assessment Method

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Abstract. The recycling of quadrotor drones is a very important process in the execution of the mission. Traditional navigation devices such as GPS and inertial navigation are limited in many cases. Complete the safety landing assessment of the four-rotor UAV. The main work is as follows: First Find relevant information to understand the development history of the four-rotor UAV and the risk of the safe landing of the four-rotor UAV and the factors affecting the landing of the four-rotor UAV, and Analyze the structure, flight principle and operation mode of the quadrotor UAV, establish the ground coordinate system and the fuselage coordinate system. Then Propose the conditions that the four-rotor UAV can land safely and the safety landing assessment method of the quadrotor UAV, and obtain the probability formula for the safe landing of the quadrotor UAV. Designing the ground environment of the landing surface of the quadrotor UAV, simulation experiments, and the probability that the four-rotor UAV will land safely in this environment.

1. Introduction
The safe landing of drones is a key part of the daily use of drones, and the success rate of blind drop is not high. Quadrotor UAV uses real-time inertial measurement unit to measure aircraft attitude in real time [1] there is a very important need for the safe landing risk assessment of drones. Therefore, we must first analyze the four-rotor drones. The structure and landing mode and then simulate the landing mode of the surface and quadrotor UAV, and propose the probability estimation of the safe landing of the quadrotor drone under blind drop. The simulation method, based on this, studies the size and landing area of the quadrotor UAV, analyzes the safe landing probability of the quadrotor UAV, and obtains the availability of the method. To get the availability of the method. The industrial drone market is developing rapidly, and the demand in various fields is growing rapidly. The civilian field will become the next growth pole of the drone industry and has a bright future [2].

2. Four-rotor UAV

2.1. The working principle of the quadrotor UAV
Pitch angle and back and forth motion: As mentioned above, the resultant force of the quadrotor is always perpendicular to the level of the propeller disk. The motor No. 1 and No. 4 are appropriately decelerated (or increased), and the motors No. 2 and No. 3 are appropriately increased (or decelerated), and the motor changes speed. [3] It remains the same to ensure that the drone does not produce yaw.
rotation. When the drone has a certain pitch angle, a resultant force is generated on the X-axis of the initial UAV carrier coordinates. The drone can move forward (backward) through a component force. [4]

![Figure 1. Four-rotor UAV front and rear motion schematic](image)

2.2. Four-rotor UAV landing mode
In this paper, the four-rotor quadrotor UAV is used as the research object. The landing process of the quadrotor UAV is: the landing process of the quadrotor drone near the ground. The first base speed is reduced to zero at a certain height, and then the engine is kept in a small speed range with a small thrust, and the four-rotor UAV slowly descends above the ground perpendicular to the ground. At this point, whether the quadrotor drone can maintain an upright posture after landing depends basically on the roughness of the landing surface [4]

3. Quadrotor UAV safe landing criterion and probability estimation method

3.1. Safe landing criterion
It is proposed that the obstacle landing height must be less than the maximum obstacle height that the quadrotor UAV can withstand \( h_{\text{max}} \). The depth of the pit must be less than the maximum depth that the quadrotor can withstand \( d_{\text{max}} \). Stone height is \( h_i \). Depth of pit is \( d_j \). The basis for the safe landing of the four-rotor UAV is

\[
\begin{align*}
    h_i &\leq h_{\text{max}} \quad i = 1,2,\cdots,u \\
    d_j &\leq d_{\text{max}} \quad i = 1,2,\cdots,v
\end{align*}
\]

(1)

\( u \) is the number of stones in the landing area of the quadrotor drone. \( v \) is the number of pits in the landing zone.

3.2. Safe Landing Probability Assessment Method
Model hypothesis: selected area is \( S \); quadrotor UAV structural model: plane square, size \( a \times a \); dangerous obstacle structure model: solid circle; quadrotor drone landing point: quadrotor drone anywhere in the landing zone Random landing. The landing zone was selected to simulate the dimensions of the quadrotor UAV and the topographical information of the landing zone. For the terrain, the landing zone landing of the quadrotor drone was randomly selected, and the landing process of the quadrotor drone was simulated several times. The landing position of the drone is determined. At each landing, the probability of a safe landing probability of successful landing is obtained by simulation [5]. In Figure 2, it can be divided into the following 9 cases.
1) Determine whether the stone or pit is in the rectangular area, the formula for judging is

\[
\left\{ \begin{array}{l}
\frac{-a}{2} < x < \frac{a}{2} \\
\frac{-a}{2} < y < \frac{a}{2}
\end{array} \right.
\]

(2)

\(z_1\) is the ordinate of the lower boundary point of the quadrotor UAV. \(r\) is the radius of a stone or pit.

2) If the stone or pit is outside the rectangular area, it is judged whether it intersects with the boundary point C of the quadrotor UAV. The discriminant is:

\[(x - x_C)^2 + (y - y_C)^2 < r^2\]  

(3)

3) If the stone or pit is outside the rectangular area, determine if it crosses the right border of the quadrotor, and the discriminant is:

\[(x - z_2)^2 < r^2\]  

(4)

4) If the stone or pit is outside the rectangular area and it is judged whether it intersects with the boundary point D of the quadrotor, the discriminant is

\[(x - x_D)^2 + (y - y_D)^2 < r^2\]  

(5)

5) If the stone or pit is outside the rectangular area and it is judged whether it intersects with the boundary point A of the quadrotor, the discriminant formula is:

\[(x - x_A)^2 + (y - y_A)^2 < r^2\]  

(6)

6) If the stone or pit is outside the rectangular area, determine if it intersects the left boundary of the quadrotor UAV. The discriminant is:

\[(x - z_4)^2 < r^2\]  

(7)

7) If the stone or pit is outside the rectangular area and it is judged whether it intersects with the boundary point B of the quadrotor, the discriminant is:

\[(x - x_B)^2 + (y - y_B)^2 < r^2\]  

(8)

8) If the stone or pit is outside the rectangular area, judge whether it crosses the upper boundary of the quadrotor UAV. The discriminant is:

\[(y - z_3)^2 < r^2\]  

(9)
Figure 2. Whether the stone or deep pit intersects with the quadrotor UAV

As long as there is a situation in the above nine cases, it can be considered that the landing of the quadrotor drone is a failure; if none of the above 8 cases occur, it can be considered that the quadrotor drone can land successfully.

In the landing area, the quadrotor drone randomly selects the landing site to land, and determines whether the landing is safe according to the landing safety determination method. If the landing is successful, the total number of successful landings will increase by 1, and the simulation will repeat \( n \) times, and the total number of successes will be recorded \( c \) times \([6]\); finally, the safe landing probability of the drone is

\[
P = \frac{c}{n}
\]  

(10)

This method is to divide the quadrotor UAV into 8 parts. When landing, the stone or deep pit has no contact with any part. The quadrotor drone will land safely when the stone or deep pit and a part the landing is a failure when there are multiple parts crossing. Then the landing process was simulated multiple times, and finally the probability of a safe landing of the four-rotor drone in this terrain was obtained.\([7]\)

4. Simulation process and results analysis

In 2008, the laboratory was divided into the machine based on time scale theory, and the controller designed by the controller was used to achieve stable flight control for each subsystem.\([8]\) Set the size of the landing area of the quadrotor UAV to \( S=10\text{m} \times 10\text{m} \), and set the size of the quadrotor UAV to \( a=b=0.5\text{m} \). The maximum obstacle size that the quadrotor drone can accept is set to \( h_{\text{max}}=0.1\text{m} \), \( d_{\text{max}} =0.1\text{m} \).\([9]\). Using the program to run 1000 times, record the number of successes, and finally calculate the safe landing probability. It can be seen that the quadrotor drone simulates landing 1000 times and successfully landed 872 times. According to formula (12), \( P=0.872 \) can be obtained.

Figure 3. Landing probability as the length
Figure 4. Landing probability as the size
As shown in Figure 3; then, keep the landing area length of 10m, change the size of the drone from 0.1m to 1m, calculate the probability of the corresponding safe landing, and draw a safe landing probability with the drone size curve. As shown in Figure 4. From the comparison of the curves in Figure 3 and Figure 4, it can be seen that the size of the landing area of the quadrotor UAV has less impact on the safe landing probability, and the size of the UAV has a greater impact on the probability of a safe landing. Therefore, in order to improve the landing success rate, the design of the quadrotor UAV should be developed to miniaturization without affecting the smooth progress of the mission.

5. Conclusion
Firstly, the conditions for the safe landing of the four-rotor UAV are proposed. How to land the four-rotor UAV safely landing, the expression of the safe landing of the four-rotor UAV is listed, and the four-rotor UAV is safely landed using the simulation software Phycharm. 1000 times, the number of safe landings of the quadrotor drone was obtained, which led to the probability that the quadrotor drone would land safely in this simulation.

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References
[1] Huang Yanni. Development of a type of UAV monitoring and control ground station detection system [D]. Nanjing University of Aeronautics and Astronautics, 2012
[2] Fang Haoran. Research on vision-based four-rotor aircraft navigation landing system [D]. Shenyang Ligong University, 2017
[3] SHAN Haiyan. Research on flight control technology of quadrotor unmanned helicopter [D]. Nanjing University of Aeronautics and Astronautics, 2008
[4] Cheng Xuegong. Design and research of quadcopter [D]. Hangzhou University of Electronic Science and Technology, 2013
[5] Huang Xiliu. Design of a four-rotor unmanned helicopter flight controller [D]. Nanjing University of Science and Technology, 2010
[6] Tu Liang. Radar characteristics analysis of multi-rotor UAV [D]. Nanchang Aviation University, 2018
[7] Gao Junjie. Research on Risk Assessment of UAV Safety Flight [D]. Civil Astronomy University, 2018
[8] Zhao Shaoqiong. Research and implementation of three-dimensional omni-directional obstacle avoidance and positioning system for indoor quadrotor UAV [D]. Beijing University of Technology, 2017
[9] Chen Lijuan, Zhou Xin, Yuan Suzhong, Wang Congqing. Vision-based estimation method for landing pose parameters of unmanned helicopters [J]. Computer Applications and Software, 2013, 30 (11): 21-23