An obstacle avoidance design of UAV based on genetic algorithm

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Abstract. In order to improve the effect of obstacle avoidance, a PID control algorithm combined with genetic algorithm is proposed. By establishing the mathematical model of UAV, the auxiliary control system of UAV is analyzed, and then the control system is optimized by genetic algorithm. Taking STM32 as the control platform, the obstacle avoidance experiment was carried out by building the experimental platform. The experimental results show that the algorithm can avoid obstacles effectively.

1. Introduction

With the development of automatic control technology, communication technology and sensor technology, UAV has been more and more widely used. The obstacle avoidance problem of UAV in flight has become very important. UAV control system mainly controls the position and attitude of UAV. The traditional control mainly uses the relative coordinate system between UAV and the ground to control the flight attitude and position\textsuperscript{[1]}. However, the actual flying environment of UAV is often complex and changeable, and the coordinate system method cannot adapt to such flying environment. Therefore, the method based on this coordinate system must continue to be optimized to ensure that the optimization method can adapt to the complex and changeable flight environment. In this way, the UAV can be controlled truly and accurately, and the obstacle avoidance can be realized\textsuperscript{[2]}. Obstacle avoidance control is an important branch of UAV research and a very important problem in UAV application. It plays an extremely important role in UAV safety inspection, UAV autonomous flight, UAV emergency rescue and other aspects. In this paper, the obstacle avoidance algorithm of UAV is studied, and the obstacle avoidance effect of UAV is improved by optimizing the control algorithm.

2. Mathematical model of obstacle avoidance system

According to many experiments and theoretical analysis, the frequently used flight posture of UAV is added to the coordinate system of UAV flight to optimize the obstacle avoidance system of UAV. These three actions can be replaced by shape. The lifting action is replaced by the east direction in the traditional coordinate system; the pitching action is replaced by the north direction; and the cross action is replaced by the direction perpendicular to the ground. The controller of UAV auxiliary obstacle avoidance system can be divided into three parts: altitude auxiliary controller, pitch auxiliary...
controller and roll auxiliary controller. Because the pitch and roll of UAV height controller are relatively simple, only the transfer function of UAV pitch and roll direction is derived here, and the transfer function is obtained [3]. Because the situation of UAV height controller is relatively simple with pitch and roll, this paper only infers the transfer function of UAV in pitch and roll directions, and obtains its transfer function as shown in Formula (1).

\[
\begin{align*}
G_x(s) &= \frac{X(s)}{U_x(s)} = -\frac{F}{ms^2} \\
G_y(s) &= \frac{Y(s)}{U_y(s)} = -\frac{F}{ms^2}
\end{align*}
\]

3. Simulation analysis of auxiliary obstacle avoidance control system

The auxiliary obstacle avoidance system of UAV mainly controls the operation position of UAV, which can be divided into two aspects. The first aspect is the control of UAV flight height, and the second aspect is the control of UAV horizontal position. And these two directions are unconnected and do not interfere with each other [4]. Therefore, PID controller can be used to control the UAV height, and its control algorithm and transfer function are shown in Formulas (2) and (3).

\[
\dot{Z} = k_p (Z_d - Z) + k_d \frac{d(z_d - z)}{dt}
\]

\[
G_z(s) = \frac{Z(s)}{U_z(s)} = -\frac{1}{7s^2}
\]

The control flow chart is shown in Figure 1.

![Figure 1. The control flow chart.](image)

Set the simulation parameters: the proportional control coefficient is -127, the integral control coefficient is -13, and the differential control coefficient is -37. The altitude control response of UAV assisted obstacle avoidance system is obtained. In the same way, the response of PID control in the two actions of pitch and roll of UAV is simulated and analyzed, and the simulation parameter settings in the two cases are shown in Table 1.

| parameter                      | kp    | ki    | kd    |
|-------------------------------|-------|-------|-------|
| Pitch action control parameters | -1.4  | -0.12 | -0.46 |
| Roll action control parameters | 1.4   | 0.12  | 0.46  |

It can be seen from the above simulation that although the auxiliary obstacle avoidance system based on PID control can reach a stable state in a very short time, and there is no oscillation after the system is stable [5]. The overshoot and steady-state time of the system under the controller can not meet the needs of practical application, so it is necessary to adjust and optimize each parameter, so an algorithm is proposed to optimize it.

4. Optimization of control parameters based on genetic algorithm

The parameters of PID can not make the UAV control reach the best state, so genetic algorithm is used to optimize the parameters of the controller, and Figure 2 is the flow chart.
Taking the roll motion of UAV as an example, the optimization rules of PID control parameters of auxiliary obstacle avoidance system are explained in detail [6]. In order to avoid excessive control energy of UAV, the optimal index of PID control parameters is determined as shown in Equation (4).

\[
J_1 = \int_0^\infty \left( w_1 |e(t)| + w_2 u^2(t) \right) dt
\]  

(4)

Set the number of iterations to 100, and the change of Formula (4) in 100 iterations is shown in Table 2.

![Figure 2. Optimization flow chart.](image_url)

It can be seen from the Figure 2 that Parameter adjustment is the core of control.

| Action               | kp   | ki   | kd   |
|----------------------|------|------|------|
| Rolling action       | 47.79| 1.47 | 3.44 |
| Ascending motion     | -47.79| -1.47| -3.44|
| Pitching movement    | -3021.26| -125.11| -230.12|

Table 2. Parameters of rolling, rising and raising actions.

Through the simulation analysis of various states of UAV in the height position direction, it can reach the stable state in the specified time, and its overshoot and stable time can meet the requirements [7].

5. Simulation and experiment

5.1. Establishment of experimental model
The space coordinate system is established with the right boundary of the left building as the origin, the horizontal direction is x-axis, the vertical direction is y-axis, and the vertical direction is z-axis; the included angle formed by the impact on the building to continue flying is \( \alpha_i + \beta_i \), when \( i=1 \), the angle is the minimum angle to bypass the first obstacle; when \( i=2 \), the angle is the minimum angle to bypass the left wall obstacle; when \( i=3 \) Represents the minimum angle when passing the right wall obstacle [8].
5.2. Model data calculation

Let a be the flight distance in x-axis direction, B be the flight distance in Y-axis direction, the horizontal distance between the obstacle and the boundary (in x-axis direction), the longitudinal distance between the obstacle and the boundary (in Y-axis direction), and the length of the obstacle. Then the following formula holds.

\[ \alpha = \arctan \left( \frac{a}{l} \right); \beta = \arctan \left( \frac{b}{l} \right) \]

\[ \alpha_2 = \arctan \left( \frac{350 - y_1}{l} \right); \beta_1 = \arctan \left( \frac{350 - y_2}{l} \right) \]

5.3. Experimental results

Through the algorithm and control idea described above in this paper, flight experiments of UAV are carried out for many times, and the flight data of UAV is shown in Table 3.

| Table 3. Obstacle avoidance data of ultrasonic straight line at low speed. |
|-----------------------------|-------|-------|-------|-------|-------|
| Number of experiments       | 1     | 2     | 3     | 4     | 5     |
| Impact times                | 2     | 3     | 4     | 2     | 5     |
| normalization               | 0.22  | 0.33  | 0.44  | 0.22  | 0.56  |
| Success (1)/ failure (0)    | 1     | 1     | 1     | 1     | 1     |
| Number of experiments       | 6     | 7     | 8     | 9     | 10    |
| Impact times                | 5     | 4     | 5     | 6     | 3     |
| normalization               | 0.56  | 0.44  | 0.56  | 0.67  | 0.33  |
| Success (1)/ failure (0)    | 1     | 1     | 1     | 0     | 1     |

According to the UAV flight data shown in Table 3, it can be seen that the UAV has a good effect of avoiding obstacles and a high success rate of avoiding obstacles in its controlled flight.

6. Conclusions

With the improvement of control theory related to multi-rotor UAV, UAV has been widely used in industry, agriculture and other fields with great potential. First of all, this paper summarizes the research status of four-rotor aircraft at home and abroad. Nowadays, unmanned aerial vehicles (UAVs) are being used more and more widely in various industries, and the UAV technology is constantly being improved. Secondly, the flight control system is designed to ensure the stability and reliability of the UAV. According to the requirements of the subject, the circuit schematic diagram of UAV aircraft was designed. After the circuit simulation, the chip was welded by reflow welding, and the hardware part of the aircraft was designed. There are the following aspects to consider: in order to enhance the stability of the hardware system, the power supply is protected in a variety of ways; a spare chip is added to ensure the effectiveness of the attitude solution. SPI peripheral interface is reserved to extend GPS, ultrasonic and other sensors. Then, this paper explains the calibration method of accelerometer and gyroscope through mathematical model, and emphasizes the importance of this step for flight control system. Following the software flow chart of the system, the mathematical model of obstacle avoidance algorithm is given, and the UAV obstacle avoidance is realized by using the classical PID control algorithm through simulation. Based on the analysis of the possible problems encountered by UAV in obstacle avoidance, this paper establishes a mathematical model, gives an evaluation index, and designs a control experiment. Large amounts of experimental data were collected. After the UAV completed obstacle avoidance, the obtained data were put into the evaluation model and scored, with scores above 90. The experiment proved that the algorithm had good obstacle avoidance effect and strong robustness in the low-speed complex environment.
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