Flight control system for quad-rotor aircraft based on improved integral separation PID
TIAN Hongpeng1,a, LI Lei2,b

1School of Xi’an University of Science and Technology, Xi’an Shaanxi, 710054, China
2School of Xi’an University of Science and Technology, Xi’an Shaanxi, 710054, China
a tian.hp@qq.com, b13484818853@163.com

Keywords: quad-rotor aircraft; PI algorithm; quaternion method; PID control algorithm

Abstract. Quad-rotor aircraft can be widely used in military and civil fields, and it is drawing a great deal of attention. Combining with PI algorithm and quaternion method, this article resolves the aircraft flight attitude and complete aircraft attitude control with improved integral separation PID control algorithm. At last, conventional PID controller, integral separation controller and improved integral separation controller are simulated in the environment of MATLAB and compared with each other. The result shows that the response rate of improved integral separation PID is faster than the conventional integral separation algorithm and the overshoot volume is also lower.

1. Introduction

Because the miniature four rotor aircraft has such prominent features as portable and convenient, simple operation, strong flexibility, vertical ascend or descent, hovering, it has a broad application prospect no matter in the field of military or in the field of civilian[1]. However, since the Quad-rotor aircraft is a under actuated system with strong coupling, nonlinear, multivariable, it becomes a key point and difficulty of aircraft research that how to establish a reasonable mathematical model and design control system to make fly stable and safe[2].

The researchers worldwide put forward such control methods as the PID control, the backstepping, and sliding mode control successively[3-5]. Among them, the PID algorithm is easy to implement. It also has good stability and high robustness at the same time. But, it still need to be improved in the corresponding speed, overshoot and stability.

2. Basic flight theory and Modeling

2.1 Basic Flight Theory.

Set the onward direction for the positive direction of the X axis, and accordingly set the direction of the movement to the left for the positive direction of the Y axis. Thus, M1 is the motor 1 that falls in the first quadrant, and the rest of the motors are tagging along the clockwise direction in turn. Among them, the M1 and M3 install the anti propeller that rotate along the clockwise direction, and the M2 and M4 install the positive propeller that rotates along the counter clockwise direction. The movement can completed by changing the motor speed to make the quad-rotor aircraft lean some degrees according to table 1.
2.2 Dynamic Model.

The movement of the quad-rotor aircraft can be seen as translational motion and rotational motion. So we can build a model of these two motions by Newton-Euler equations.

$U_1$ is used to express the sum of the body's lift in motion. $U_2$ is used to express the rolling torque. $U_3$ is used to express the pitching moment. $U_4$ is used to express the yaw moment. The rotary inertia of the body around the aircraft coordinate system is expressed by $I_x$, $I_y$ and $I_z$, and the angular velocity of the shaft is expressed by $\dot{\theta}$, $\dot{\phi}$, $\dot{\psi}$. Then the final dynamic model of the quad-rotor aircraft can be expressed as Formula 1 under the condition of ignoring resistance coefficient in slow flight\[^6\].

\[
\begin{align*}
\dot{x} &= \frac{(\sin \psi \sin \phi + \cos \psi \sin \theta \cos \phi)U_1}{m} \\
\dot{y} &= \frac{(\sin \psi \sin \phi \cos \phi - \cos \psi \sin \phi)U_1}{m} \\
\dot{z} &= \frac{(\cos \phi \cos \theta)U_1 - mg}{m} \\
\dot{\theta} &= \frac{[U_2 + \dot{\theta} \psi (I_y - I_z)]}{I_x} \\
\dot{\phi} &= \frac{[U_3 + \dot{\phi} \psi (I_z - I_x)]}{I_y} \\
\dot{\psi} &= \frac{[U_4 + \dot{\phi} \psi (I_y - I_z)]}{I_z}
\end{align*}
\] (1)

3. Controller design

Since quad-rotor aircraft is a nonlinear complex system of under actuated, strong coupling and multivariable , it is particularly important to design a highly efficient and stable control system to achieve the control of this system. The control logic of the control system is shown in Fig. 1.

3.1 Attitude Algorithm.

The control system of quad-rotor aircraft is divided into two stages of attitude control and attitude control. The first stage is to calculate the attitude of quad-rotor aircraft. Due to the performance of
the gyroscope in low dynamic state is good but it will appear cumulative error as time goes on, it
needs to be corrected. The output of the accelerometer is used to the effect of drift.

**PI algorithm to correct angular velocity.** At present, the fusion algorithm has Calman filter
algorithm, first order complementary filtering algorithm, etc. In this paper, the PI control method is
used to eliminate the error of vector product cumulative errors, and then the attitude algorithm is
carried out by using the four element method\[^8\].

The error of the angular velocity can be expressed by the vector product of the acceleration and
the reference vector as follows:

\[
e = (e_x, e_y, e_z)
\] (2)

PI control method is a method that only keep the proportion and integral term of the PID control.
The cumulative drift of the formula 3 can be used as a correction amount of \( \omega \), then the formula 4
is obtained as follows:

\[
e(t) = e(t-1) + K_i e(t-1) + K_p e(t-1)
\] (3)

\[
\omega' = \omega + e(t) 
\] (4)

In formula 4, the \( \omega \) is the angular velocity. The value is obtained by the gyroscope. \( \omega' \) is the
angular velocity after correction.

**Four element attitude calculation.** According to the literature[9], the transformation from four
elements number converted into Euler angles as follows:

\[
\begin{align*}
\phi &= \arctan(2(q_3q_2 - q_1q_4),1 - 2(q_2^2 + q_3^2)) \\
\theta &= \arcsin(2(q_1q_3 + q_2q_4)) \\
\psi &= \arctan(2(q_3q_4 + q_2q_1),1 - 2(q_2^2 + q_3^2))
\end{align*}
\] (5)

As the body’s attitude in a given moment can be expressed with \( A = (\theta, \phi, \psi) \), we can get the
current attitude of the aircraft.

### 3.2 Attitude Control.

Combine the results of the first stage and the objective attitude to calculate the difference, and
then use the PID method to get the output of the motor. Attitude control PID flow chart as shown in
Fig. 2:

![Attitude control PID flow chart](image)

As the basic idea is that set two threshold \( a \) and \( b \) (\( a < b \)). When the error is greater than \( b \), set the
integral control coefficient zero to cancel the integral function; when the error between the two
threshold, set the cumulative coefficient zero so that the \( e(k) \) no longer accumulated to maintain
the original value; when the error is less than \( a \), use the complete PID control. Expression as
shown in formula 6.

\[
u(k) = K_p e(k) + \beta K_i \sum_{j=0}^{k-1} e(j) + \alpha e(k) T + K_d \frac{(e(k) - e(k-1))}{T}
\] (6)

In this formula, the \( \beta \) is the integral term control coefficient whose value is shown in the
formula 7. The \( \alpha \) is the accumulation term coefficient, and its value is shown as the formula 8.
The \( T \) is the sampling period.

\[
\beta = \begin{cases} 
0 & e(k) > b, \\
1 & e(k) \leq a.
\end{cases}
\] (7)

\[
\alpha = \begin{cases} 
0 & a < e(k) < b, \\
1 & e(k) \leq a \quad e(k) \geq b.
\end{cases}
\] (8)
Among them, a and b are adjusted according to the test, artificially set the threshold of greater than zero (a<b).

4. Simulation analysis

The conventional PID controller, integral separation controller, and improved integral separation controller are simulated separately in the environment of Matlab. The results are shown in Fig. 3:

![Fig. 3 simulation results](a) conventional PID control (b) integral separation algorithm (c) improved algorithm

PID parameters are set as that \( k_p \) is equal to 0.45; \( k_i \) is equal to 0.0048; \( k_d \) is equal to 12; threshold \( a \) and \( b \) is 0.3 and 0.7 respectively. What can be seen from Fig. 3 is that when using the conventional PID control, the system response time is longer, and the oscillation frequency is more. But when using the integral separation algorithm, the system oscillation frequency is reduced, and the regulating time is shortened. The improved integral separation algorithm has a best effect that almost no oscillations and the shortest adjusting time.

5. Summary

Based on an overview of the principle of aircraft flight, this paper uses the PI algorithm combined with the four element method to calculate the flight attitude of the aircraft, and use the improved integral separation PID control algorithm to complete the attitude control of the aircraft. Finally the simulation and comparison of the conventional PID controller, integral separation controller and improved integral separation controller are complete in the environment of MATLAB. The results show that the improved algorithm of integral separation can be overcome the shortcoming of can not eliminate the shortcomings of static caused by not enough integral function. The system has almost no oscillation and adjustment time is shorter than the conventional PID and integral separation PID. Therefore, controller designed by the improved integral separation PID algorithm can make the aircraft fly more stable.

References

