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Design of flight control system of Quad Tilt Rotor UAV based on PID algorithm

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Abstract. This research focuses on the quadrotor tiltrotor unmanned aerial vehicle and considers various usage scenarios such as battlefield and transportation environments, as well as flight stability issues in complex meteorological environments. A PID control algorithm for rotor angle control of quadrotor tiltrotor unmanned aerial vehicles is designed, which is suitable for different usage scenarios and meteorological conditions.

Keywords: PID Algorithm, Quad Rotor UAV, Tilt Rotor Aircraft, Flight Control System, MATLAB Simulation.

1. Introduction

1.1. Background information

With the development of modern technology, the application scenarios of aircraft in daily life are rapidly expanding, especially unmanned aerial vehicles. The proportion of drones in various aspects of society, such as agriculture, commerce, military, civilian, and other fields, has increased. From the perspective of technological breakthroughs, technological breakthroughs related to drones have also emerged frequently in recent years. For example, the fuselage's lightweight design is becoming increasingly significant, and the efficiency of the UAV motor and battery discharge efficiency has been fully improved. Especially in the military field, technological breakthroughs are very significant. The full name of the unmanned aerial vehicle is "Unmanned Aerial Vehicle", abbreviated as "UAV".**[1]** It is an unmanned aircraft operated by radio remote control equipment and self-contained program control devices. It involves sensors, communication, information processing, intelligent control, and aviation power propulsion technology. It is the product of high-technology content in the information age. Moreover, the VTOL UAV has the advantage of not relying on runway takeoff and landing, hovering, etc. Compared with traditional aircraft, it has the characteristics of low operating cost, large flexibility in use, and less support equipment. Unmanned aerial vehicles can be roughly classified into fixed wing, rotor (helicopter, multi-rotor) [2], and flapping wing based on wing configuration. Among them, the characteristics of the rotorcraft are very prominent. The rotorcraft can take off and land at a fixed point, which does not require high takeoff and landing site conditions. However, the fixed-wing UAV is prone to stall, unable to hover in the air, and the related technology of the Ornithopter is not mature at the current stage. So there is a significant demand for rotary-wing drones in both civilian and military fields. Tilt Rotor UAV is a new type of composite rotor aircraft. Its Airplane modes are divided into rotor,

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transition, and fixed-wing modes [3]. It combines the characteristics of VTOL, hovering in the air, high-speed cruise, and long endurance of fixed-wing aircraft.

1.2. Existing problem

Traditional quadcopter drones also have limitations in the range of onboard cameras, such as the impact on shooting accuracy of throwing weapons when mounted under the rack. Quadcopter drones do not have good stability under complex meteorological conditions, and the low payload of quadcopter drones [4]. The traditional Tiltrotor is inherently difficult to take off and land stably under complex weather conditions in the aerodynamic design of the fuselage, and the Tiltrotor relies on the wing surface to generate lift when the engine is in the horizontal position.

For the above problems, if the concept of quadrotor UAV and Tiltrotor is combined, appropriate solutions will be provided for the problems mentioned above. Tiltrotor can have a higher range, less vibration, and can attach a larger load and a wider flight envelope [5]. The quadrotor UAV can provide better maneuverability and better coping mechanism for complex weather conditions. Moreover, the reasonable combination of quadrotor UAV and Tiltrotor can effectively exert the common advantages of the two designs, and effectively avoid the common problems of quadrotor UAV and rotary wing UAV This control system can provide assistance for the stability of drones during flight, and has a driving role in drone detection, drone transportation, and other fields. It makes drones more accurate in dropping supplies and weapons and provides new equipment and ideas in military, civilian, agricultural, and other fields.

Based on the existing problems of the four-rotor UAV and the advantages of the four-rotor UAV, as well as the advantages of Tiltrotor, this research will explore the flight control system design of the unmanned four-rotor Tiltrotor based on the PID algorithm, and explore a set of PID control systems suitable for the aerodynamic layout of the current UAV and Tiltrotor.

2. Literature Review

2.1. Foreign literature review

According to foreign media reports, in general, the research on Tiltrotor is concentrated in the United States. The United States has successively developed XV-3 Tiltrotor, XV-15 Tiltrotor, V-22 Osprey Tiltrotor, etc. [6], but most of these models rely on wing configuration, adopting the scheme of combining fixed-wing aircraft with helicopters, and are greatly affected by crosswind.

2.2. Domestic literature review

Based on the domestic media reports and domestic literature in recent years, great progress has also been made in Tiltrotor in China. For example, the Rainbow 10 tilt-rotor UAV developed by China Aerospace Group in 2018, a series of tilt-rotor UAVs developed by Shenzhen Zhihang Company, the three-axis six rotor tilt-rotor UAV developed by the "New Concept coaxial Tiltrotor" team of Beihang University, and the concept aircraft of four rotor tilt-rotor UAV proposed by AVIC Helicopter Institute in 2013, The feasibility of combining Tiltrotor with quadrotor UAV is further demonstrated.

3. Method

The development of this control system adopts Kinematics modeling for UAV, adds a tilt-rotor physical module and tilt-rotor control module to the traditional four-rotor UAV, and simulates the motion feedback of tilt-rotor UAV in MATLAB, to obtain a control system suitable for tilt-rotor four-rotor UAV.

3.1. Modeling of a four-rotor tiltrotor unmanned aerial vehicle

To investigate and verify the changes in airflow at the lower part of the tiltrotor rear frame, as well as the impact of changes in aerodynamic layout and shape behind the tiltrotor on the control of the unmanned aerial vehicle, mathematical modeling of the flight state of the drone before and after the

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tiltrotor is conducted, The rotor tilt angles of the four rotors are introduced into the mathematical modeling and Tiltrotor simulation system as parameters, and the output of the system will directly reflect the control accuracy level of the PID control algorithm for this system.

3.2. Kinematics modeling of four-rotor tiltrotor UAV(Fig1)

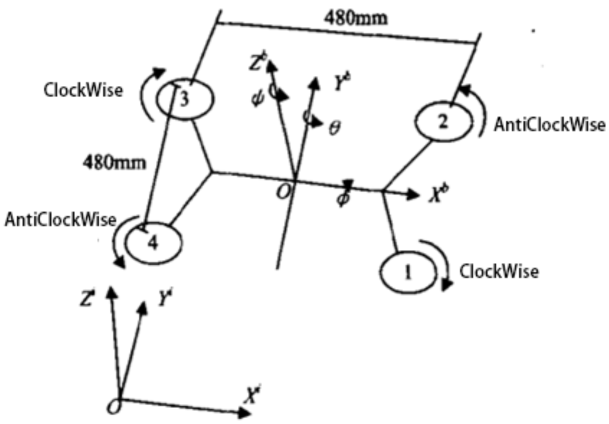

Figure 1. Kinematics modeling of four-rotor tiltrotor UAV.

3.3. Kinematics Force Analysis of Quadrotor UAV

Closing external torque:

$$\begin{aligned}\Sigma M^b &= -\gamma_r \Omega^b + \begin{bmatrix} \alpha k U_1 \\ \alpha k U_2 \\ \alpha U_3 \end{bmatrix} \\ &= -\gamma_r \Omega^b + \begin{bmatrix} \alpha k(\omega_1^2 - \omega_2^2 - \omega_3^2 + \omega_4^2) \\ \alpha k(\omega_1^2 + \omega_2^2 - \omega_3^2 - \omega_4^2) \\ \alpha(\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2) \end{bmatrix}\end{aligned}$$

Four-rotor UAV Kinematics formula:

$$\begin{cases} \ddot{x} = (C_\varphi C_\theta C_\psi + S_\varphi S_\psi)\frac{1}{M}\sum_{j=1}^{4} k\omega^2 - \frac{R}{M}(\gamma_t(R^{\mathrm{T}}\vec{v}^i)) \\ \ddot{y} = (C_\varphi C_\theta C_\psi - C_\psi S_\varphi)\frac{1}{M}\sum_{j=1}^{4} k\omega^2 - \frac{R}{M}(\gamma_t(R^{\mathrm{T}}\vec{v}^i)) \\ \ddot{z} = \frac{C_\varphi C_\theta}{M}\sum_{j=1}^{4} k\omega^2 - \frac{R}{M}(\gamma_t(R^{\mathrm{T}}\vec{v}^i)) - g \\ p = \dot{\varphi} - \dot{\psi}\sin\theta \\ q = \dot{\theta}\cos\varphi + \dot{\psi}\sin\varphi\cos\theta \\ r = -\dot{\theta}\sin\varphi + \dot{\psi}\cos\varphi\cos\theta \\ \dot{p} = qr(\frac{I_y - I_z}{I_x}) + \frac{l}{I_x}U_1 - \frac{R\gamma_t R^{\mathrm{T}}}{I_x}p + \frac{J_r}{I_x}qU_3 \\ \dot{q} = pr(\frac{I_z - I_x}{I_y}) + \frac{l}{I_y}U_2 - \frac{R\gamma_t R^{\mathrm{T}}}{I_y}q + \frac{J_r}{I_y}pU_3 \\ \dot{r} = pq(\frac{I_x - I_y}{I_z}) + \frac{1}{I_z}U_3 - \frac{R\gamma_t R^{\mathrm{T}}}{I_z}r \end{cases}$$

Schematic diagram of tiltrotor modeling:

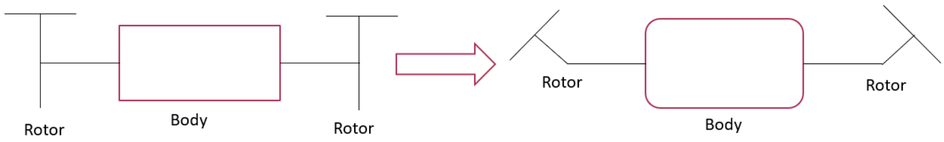

Figure 2. Example of shape of tilt rotor1.

Or

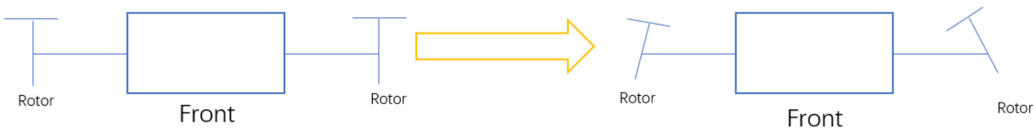

Figure 3. Example of shape of tilt rotor2.

3.4. Verification of the effectiveness of the algorithm

Before tilting the rotor of a four-rotor unmanned aerial vehicle, the air turbulence under the frame in the simulated environment was measured and compared with the net air area under the frame after tilting the rotor. The time taken for the body to transition from unstable to stable before tilting the rotor and the time taken for the body to transition from unstable to stable after tilting the rotor were compared, Evaluate the benefits of this control system for this type of drone and its impact on the stability of the rotorcraft to determine the differences.

Logic diagram of the control program:

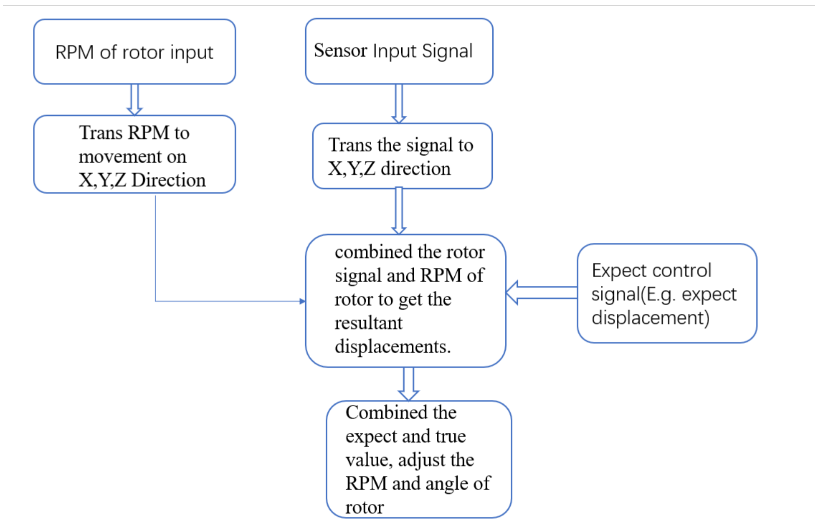

Figure 4. PID Control Logic.

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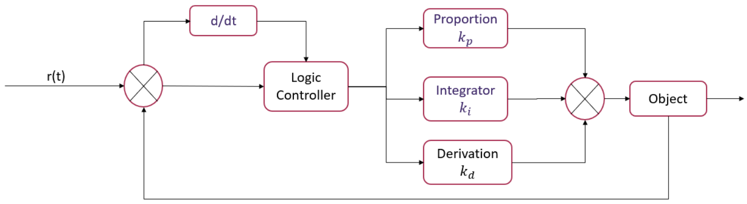

Figure 5. Logic of PID control.

In this study, sensors were installed at the tilt rotor of the drone to read the tilt angle of the rotor. After calculation and mixing, it was input into the total calculation system. After adding expectations, PID control was used to achieve the desired results.

General diagram of PID control program:

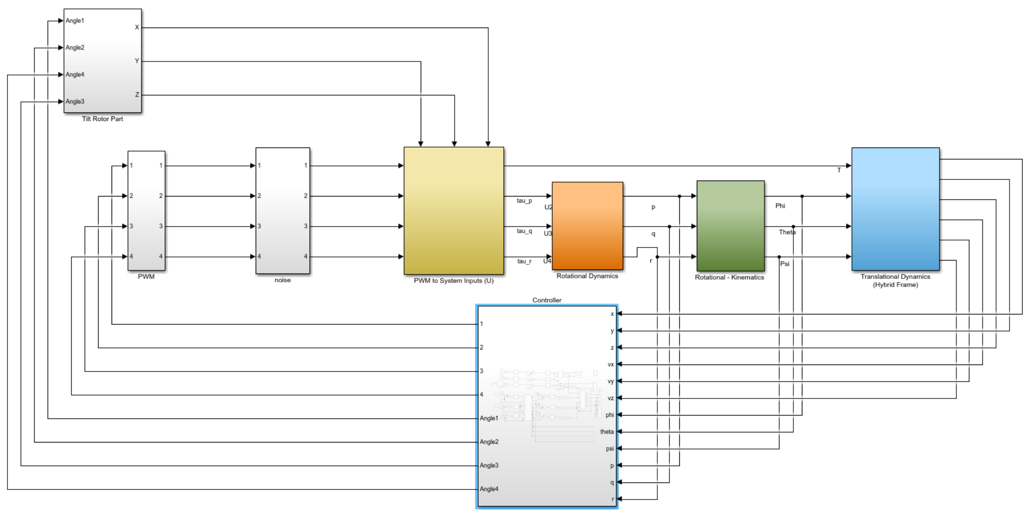

Figure 6. General diagram of control algorithm.

By analyzing the angle of each rotor and the output speed of the fan, it is determined that each fan produces; The actual displacement is then calculated to obtain the expected output value after applying the expectation, which is applied to each motor to achieve the expected displacement and movement of the drone.

3.5. *Test route*

Establish a mathematical simulation model of cascade PID in Simulink, add a rotor tilt control module to the cascade PID control so that the system can make corresponding actions for tilt-rotor operation and displacement operation after inputting expected values, and design aerodynamic adjustments suitable for tilt rotor in the algorithm.

Output diagram of PID program:

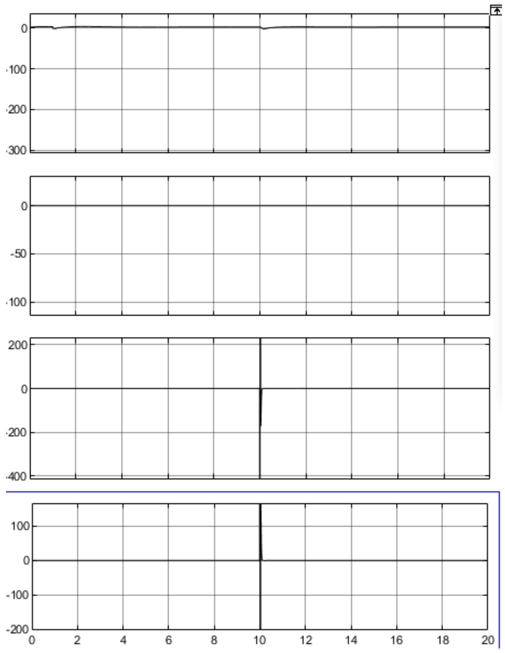

Figure 7. Output of rotors.

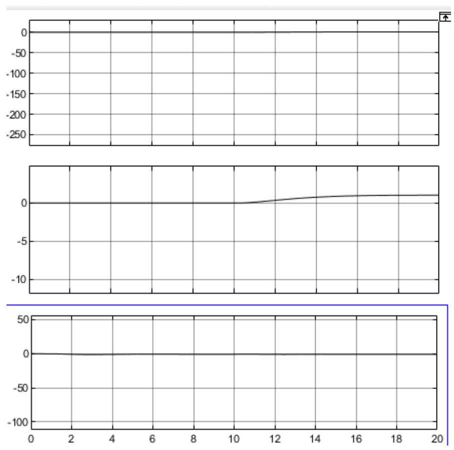

Figure 8. Change Of Displacement.

4. Conclusion

By using this PID control system to adjust the fan speed, fan tilt angle, and pitch angle changes, the stability of the four rotor tiltrotor unmanned aerial vehicle in complex weather and meteorological environments has been improved, as well as the response to instantaneous complex meteorological conditions at any stage of takeoff, cruise, target strike, and landing, such as strong crosswind, To solve the problem that Tiltrotor and traditional unmanned aerial vehicles do not have good stability under complex weather conditions. Meanwhile, based on PID control, it is possible to find appropriate balance points in speed, load, and stability by controlling the tilt angle of each rotor, thereby improving the flight efficiency of the four rotor tilt rotor unmanned aerial vehicle.

References

[1] HuangZhi. UAV Development and UAV Technology 2021(7):23-24
[2] WU Yongcheng, CHENZili, JIjinjiang.Quad-Tilt Rotor UAV Aerodynamic Characteristics. 2020,41(3):72-75. DOI:10.11809/bqzbgcxb2020.03.014.

[3] HuangZhi. UAV Development and UAV Technology2021(7):23-24

[4] XIONG Hang, LI Bo, QIN KE al., etc. Fixed-Time Integrated Attitude-Position Control of a Tilt Quadrotor UAV. 2022,40(6):1034-1046. DOI: 10.3969/j.issn.0255-8297.2022.06.013.

[5] WU Yongcheng, CHEN Zili, SU Lijun.al.etc. Longitudinal attitude control of quad tilt rotor UAV based on fuzzy LADRC. 1002-0853(2020)03-0028-06

[6] DU Siliang, WANG Ce, TANG Zhengfei.al.etc. Numerical Analysis of Aerodynamic Interference of Rotor/Fuselage in Transition State of Tilting Four-Rotor UAV 1005-2615(218)02-0179-07