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Comparison of anti-interference ability between PID controller and ADRC controller in UAV operation at ocean

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Abstract. With the maturity of UAV technology, drones can carry different instruments in the air to help people complete their work more efficiently. However, different working environments also bring different challenges to UAV control systems. This paper mainly discusses the quadrotor UVA and compares the stability of the Proportional Integral Derivative (PID) controller and Active disturbance rejection controller (ADRC) under the disturbance of gusts at sea. The flight principle of the quadrotor and the dynamic model of the quadrotor will be discussed on this basis. Then the composition and mathematical formula of the PID and ADRC controllers are introduced and compared. In general, this paper focused on the anti-jamming ability of different controllers under the influence of gust, which shows that although the ADRC controller has a more complex system and tedious parameter adjustment process in comparison with the PID controller, it has excellent anti-gust interference ability and can better serve the offshore operation of UAV.

Keywords: PID, ADRC, UAV, Anti-Interference, ocean operation.

1. Introduction

An unmanned aerial vehicle is a remote-controlled aerial vehicle that does not require a driver to board a plane. It is widely used in military and civilian applications. With the continuous development of technologies such as BIM, drones, and 3D scanning, drones can be used as a new type of data acquisition tool with the advantages of aerial operations and automation. The quadrotor is an ideal simulation object because it is simple in structure and easy to establish the model, compact in volume and easy to establish the coordinate system, light in weight, and easy to test.

Traditional sea area monitoring requires technicians to take a boat to a designated area to use instruments to measure and monitor. In this process, marine activities are inseparable from ships as carriers and tools. In addition, the area a worker can monitor is limited. With the maturity of UAV technology, the UAV as a platform can carry different equipment according to the purpose. This makes drones a new and better option for maritime surveillance.

But due to the more variable sea surface climate, an additional challenging requirement was introduced: the stable flight of the drone under the influence of gusts of wind. In order to achieve a relatively stable airborne capability of UAVs, a control system with strong anti-jamming ability is needed.

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This paper focuses on studying the disturbance resistance of the PID controller and ADRC controller under gust interference. This paper compares the basic control theory and the results under MATLAB/Simulink simulation to assess the performance and make reasonable suggestions.

2. UAV structure and hover principle

The quadcopter drone has four independent brushless DC rotors and fixed-tilt propellers installed at the four corners. Two of the four propellers rotate clockwise, and two rotate counterclockwise, as shown in Figure 1. The dynamics of the quadcopter UAV generally consider two frames of reference, namely the reference frame of the fixed ground and the frame of reference of the fuselage. We make the assumption that the origin of the fixed coordinate system is located at the quadcopter's center of gravity, where the inertial measurement unit (IMU) is located.

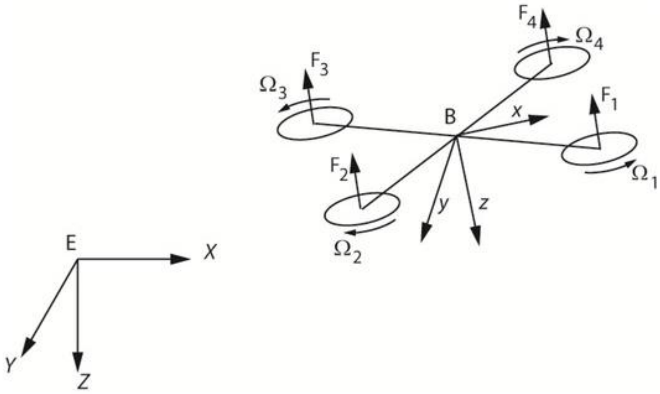

Figure 1. Quadrotor Configuration (E—Earth frame; B—body fixed frame) [1].

3. Dynamics model of quadrotor

To be able to simulate the quadrotor UAV in MATLAB, it is necessary to understand the Quadrotor Rotor's dynamic model and find out the variables that control the UAV attitude. Assuming that the navigation coordinate is a geographic coordinate system and its origin is selected at the initial UAV position, the origin of the body coordinate system and the drone's core detector IMU are located on the quadrotor's center of mass.

3.1. Position dynamics model

In the equation of translational motion of the quadrotor, the position change is taken as the output quantity, but it contains the parameters of the rotation part. The purpose of establishing the quadrotor model is to analyze the position and attitude changes of the quadrotor under the condition of external force and torque [2]. The brushless motor provides tension and torque for the quadrotor UAV, and the encoder can measure the speed and angular velocity. The kinematics model of UAV velocity and angular velocity is established to obtain the position and attitude of the quadrotor.

The acceleration state information in the body coordinate system can be obtained by the IMU sensor. After transfer to the center of the Earth coordinates. The rotation matrix can be used to calculate the angle of yaw that is rotated around the Z-axis, the angle of pitch about the Y-axis, and the angle of roll about the X-axis.

According to Newton's second law, the position dynamics model is obtained [3]:

$\dot{v}_x$ is the distance of x-axis; $\dot{v}_y$ is the distance of y-axis; $\dot{v}_z$ is the distance of z-axis; φ is angle of yaw; θ is the angle of pitch; γ is the angle of roll; m is the mass; T is the total lift of the four propellers; g is Gravity of Earth.

$$\begin{cases} \dot{v}_x = -\frac{T}{m}(\cos\varphi\sin\theta\cos\gamma + \sin\varphi\sin\gamma) \\ \dot{v}_y = -\frac{T}{m}(\cos\varphi\sin\theta\cos\gamma - \sin\varphi\sin\gamma) \\ \dot{v}_z = g - \frac{T}{m}\cos\varphi\sin\theta \end{cases} \quad (1)$$

3.2. Posture dynamics model

Rotation around the center of mass is described by Euler's equation as follows.

$$G_a + \tau = J\dot{w}^b + w^b \times Jw^b \quad (2)$$

w^b is the angular velocity in reference to the body coordinate system; J is the Inertia matrix. Use q p r Represents the three components on the body axis separately. G_a is Gyroscopic moment, When the motor is rotating at high speed, it can be regarded as a stable individual, with the ability to keep its axial direction unchanged. Therefore, gyro torque can prevent external forces from changing the direction of the gyro axis.

After opening each item in Equation (2) and moving the items, we can get:

$$\begin{cases} \dot{p} = \frac{I_y - I_z}{I_x} qr - \frac{J}{I_x} q\Omega + \frac{U_2 l}{I_x} \\ \dot{q} = \frac{I_z - I_x}{I_y} pr + \frac{J}{I_y} p\Omega + \frac{U_3 l}{I_y} \\ \dot{r} = \frac{I_z - I_y}{I_z} pq + \frac{U_4}{I_z} \end{cases} \quad (3)$$

Where I_x is the moment of inertia in X-axis; I_y is the moment of inertia in Y-axis; I_z is the moment of inertia in Z-axis.

After the rigid body model of quadrotor flight control is established, the controller can be designed according to this model.

4. Control strategies

In the absence of a control system, direct use of a signal drive motor to drive propeller rotation to generate control forces will lead to too fast or too slow dynamic response, overshoot or insufficient control phenomenon, multi-rotor not successfully complete take-off and hovering action. In order to solve these problems, it is necessary to add the controller algorithm into the control system loop, so that the control of the multi-rotor system can achieve the phenomenon of rapid dynamic response, neither overshoot nor lack thereof [4].

4.1. PID-based control

PID control algorithms an automatic adjustment system that obtains the error value through the real-time data of the controlled object and the comparison results provided [5]. With this value, as the system can be adjusted to reach a stable state. The principle of PID controller is to make the error value of the target and the same as the current value by the line of proportional adjustment, integral adjustment and derivative adjustment. When the current value is disturbed, the PID will be adjusted by error. The output response of PID controller is expressed by the formula [6].

$$u(t) = K_{Pe}(t) + K_I \int_0^t e(t)\,dt + K_D \frac{de(t)}{dt}$$

(4)

In the formula (4), K is the gain value. K_{Pe} is a proportional, which is a control effect proportional of the error value. K_I is the integral term that removes the error remaining during a constant state. K_D is a derivative constant that limits the sudden change of the output value to improves the control stability and reducing the overshoot.

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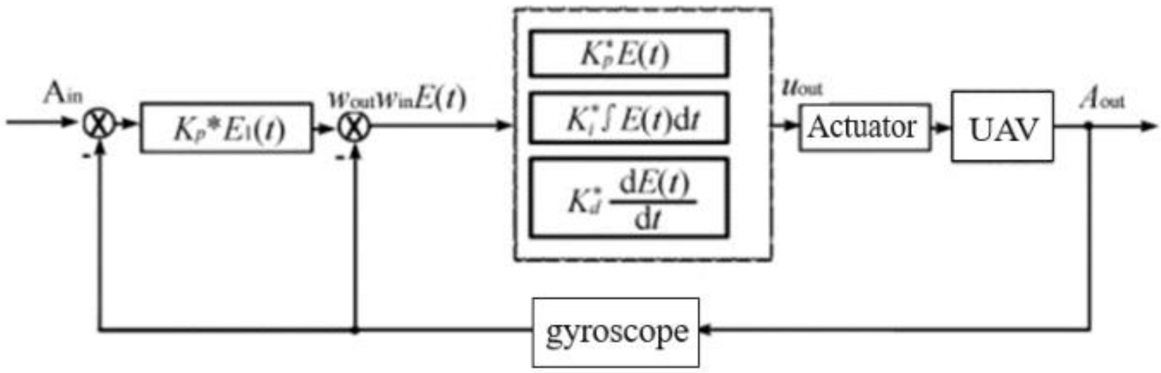

Figure 2. The control framework of the cascade PID controller.

Figure 2 shows an ideal cascade PID controller. The input of the outer loop angle control system is the attitude angle of the UAV, and the input of the inner loop angular velocity control system is the attitude angular velocity (P), the integral of the attitude angular velocity (I), and the differential of the attitude angular velocity (D).

4.2. Active disturbance rejection control (ADRC) algorithm and control framework

ADRC control algorithm is an improved version of PID control algorithm, ADRC mainly provides three more modules to improve the shortcomings of PID algorithm. The ADRC controller can be divided into three main components:

1. Tracking differentiator (TD): extracts and differentiates a continuous signal from a discontinuous or noisy signal, enabling speedy tracking of the reference input without overshooting [7].

2. Extended state observer (ESO): takes both the input and the output of the plant as input to observes the internal state of the plant and the total disturbance it receives, and re-estimates the feedback of the controller [8].

3. Nonlinear state error feedback (NLSEF): is a nonlinear combination of the differential inputs (v1, v2) of the TD and the errors (e1, e2) of the ESO, and then outputs the total disturbance [9].

Figure 3 shows the system of the ADRC controller, where V represents the input command, u represents the quadrotor input and y represents the quadrotor output.

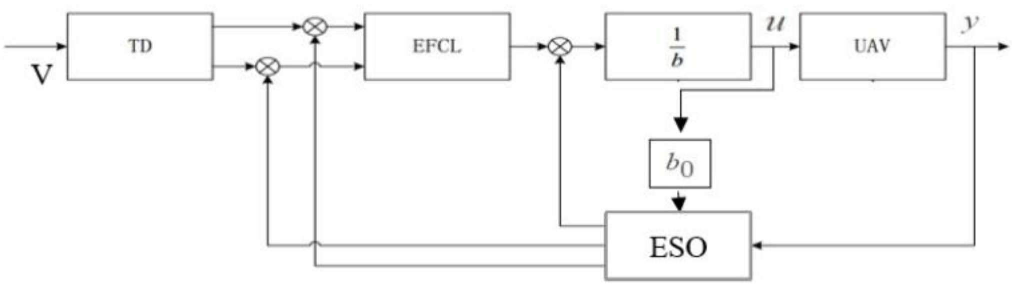

Figure 3. The Control Framework of ADRC Algorithm.

4.3. Comparation of ADRC algorithm and PID algorithm

The PID control principle is simple, robust, easy to implement, and mature technology. However, when the initial error is large, it is easy for PID to take into account the disagreement between rapidity and overshoot, and it takes a lot of time to debug parameters. ADRC introduced the tracking differentiator (TD) to design the transition process of the error signal and output a transition signal to track the target signal. The problem of signal mutation can be avoided from the source. In addition, the ADRC has an expanded state observer (ESO), which can make an estimation of the total disturbance more accurately and also modify the control quantity.

From the point of view of the algorithm, PID algorithm is relatively simple and easy to implement, but because of the relatively simple structure, each parameter will have a great impact on the feedback, engineers need more time to adjust the parameters to achieve better performance. Because the ADRC algorithm adds TD module, it can smooth the input signal. In addition, the ESO module can observe the acceleration of the four-axis UAV, so that the UAV can move more smoothly. These extra modules make the ADRC system have strong anti-jamming, and there is almost no requirement on the controlled object's mathematical model.

5. Comparison of anti-interference ability between PID controller and ADRC controller

This paper mainly discusses the performance of the maritime UAV, so it will compare the ability of the PID controller and the ADRC to adjust the attitude of the UAV under gust disturbance. This article will cite the experimental data from the paper by Tao Niu and Guojun Zhu for analysis. Combined with experimental data, this paper will give suggestions for controller selection during UAV exploration.

In the paper, Guojun Zhu points out that gust disturbance is in close similarities to pulse disturbance, and uses MATLAB as a platform to build the performance of different controllers under simulation conditions [10]:

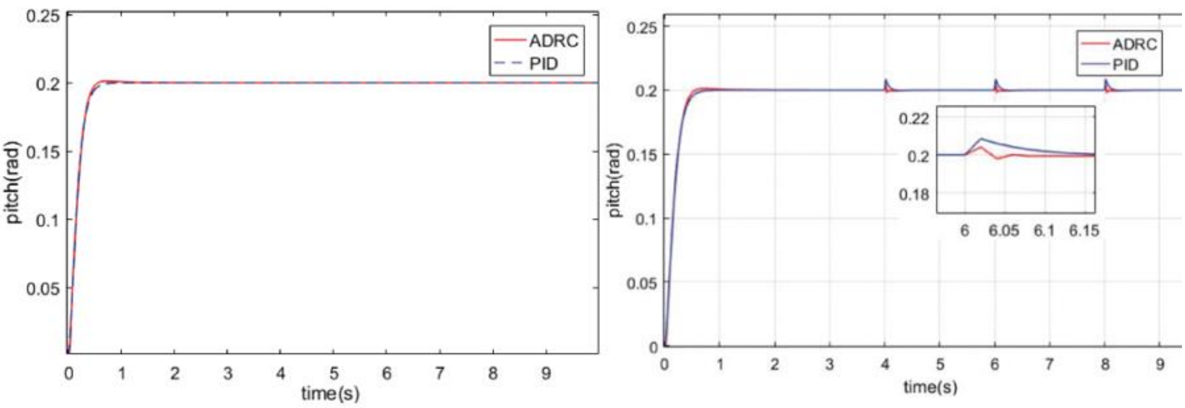

Figure 4. Step response without disturbance in MATLAB (Left), Step response with pulse disturbance in MATLAB (Right) [10].

The simplified ADRC system used in the experiment is simulated by MATLAB. In Figure 4, both PID and ADRC are excellent in the case of no interference, and can reach a stable state in about 0.8s. When there is pulse interference as shown in the right side of Figure 4, the interference of the gust wind has a big impact on the PID controller. When the interference occurs, there will be a big jump in the response signal. PID utilizes PI to adjust the response back to steady state, which takes 0.15 s. whereas it takes ADRC only 0.06s to reach the steady state due to ESO system's ability to detect disturbance and provide feedback to system in less time ADRC has strong anti-interference ability.

Tao Niu mention and establishes a mathematical model of wind gusts to restore the performance of UAVs in real life and adds a simulation of the gust wind disturbance to the controller system [11].

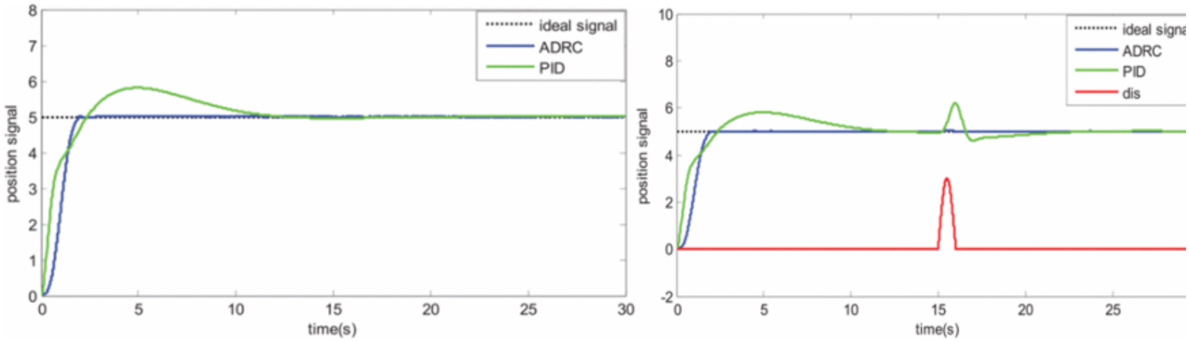

Figure 5. Response of PID and ADRC without gust wind (Left), The response curves with gust wind (Right) [11].

The experiment uses a relatively complete ADRC system, but there are certain problems in the experiment with the PID parameters. As shown in Figure 5, the PID parameters have the problem of the integral being too high, which leads to a large error in the PID experimental data, so we mainly observe the data of ADRC. In Figure 5, under the interference of the gust model, ADRC performs excellently without obvious fluctuation.

In summary, the simulation results and analysis show that the active disturbance rejection has a stronger anti-gust interference ability in comparison with the PID controller. For offshore UAVs, the ADRC system has more capability to maintain balance under the interference of sea breezes, which allows the UAV to deliver more accurate information.

6. Conclusion

This paper first introduces the potential of UAVs to enhance maritime supervision, but due to the impact of wind gusts in surface operation, UAVs need stronger stability and anti-interference. The article focuses on the choice of controller for this problem. Firstly, this paper shows the dynamic model of the quadrotor. Then, based on the math model, the principle of the PID controller and ADRC are introduced. PID technology is relatively mature and is applied to most UAVs. The control logic is simple and convenient to change and optimize parameters. Compared with ADRC, parameter setting is relatively simple, but it’s time-consuming to find the most suitable parameters, and anti-gust interference ability is relatively weak. It takes more time to reach a stable state. Although the relative ADRC has many parameters and manual parameter adjustment is too complicated, attitude control has better stability and anti-interference ability. Parameter adjustment can be optimized through manual parameter adjustment experience and formula derivation. Therefore, in general, ADRC is a better choice for UAV maritime supervision. In this paper, a combination of experiment and theory is used to compare PID and ADRC. However, due to the experimental data borrowed from other articles, the detailed simulation parameters cannot be adjusted and optimized. After that, the simulation experiment will be redesigned and completed.

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