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Design of Attitude Control Law for Coaxial Helicopter Based on Active Disturbance Rejection Control

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Abstract

In this paper, a coaxial twin rotor unmanned helicopter is taken as the research object to study the anti disturbance problem during the homing approach and landing phases of unmanned aerial vehicles. In order to improve the anti disturbance performance of coaxial helicopters against external disturbances, an active disturbance rejection controller (ADRC) is selected to design the attitude control law for coaxial helicopters in the marine landing environment. An improved particle swarm optimization algorithm was designed to optimize the parameters of the active disturbance rejection control law. The simulation results show that the improved particle swarm optimization algorithm can significantly improve the parameter tuning speed and accuracy; The auto disturbance rejection control law with optimized parameters has good dynamic response and robustness in strong interference environments.

Introduction

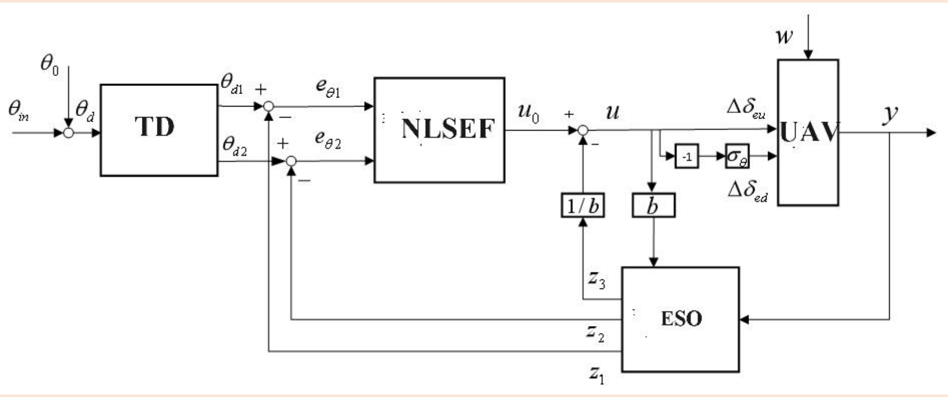
Coaxial helicopters face significant external disturbances during sea operations, necessitating accurate mathematical models and control strategies for stable landing. The study explores the integration of ADRC for enhanced landing performance under high sea conditions.

Method

Modeling Analysis: Kinematic and dynamic models of the helicopter are established to understand its natural behavior through open-loop simulation.

$$\begin{cases} \dot{u} = vr - wq - g\sin\theta + (X_{ur} + X_{fus} + X_{dr})/m \\ \dot{v} = wp - ur + g\sin\phi\cos\theta + (Y_{ur} + Y_{fus} + Y_{dr})/m \\ \dot{w} = uq - vp + g\cos\phi\cos\theta + (Z_{ur} + Z_{fus} + Z_{dr})/m \\ \dot{p} = qr(I_y - I_z)/I_x + (L_{ur} + L_{dr})/I_x \\ \dot{q} = pr(I_z - I_x)/I_y + (M_{ur} + M_{dr})/I_y \\ \dot{r} = pq(I_x - I_y)/I_z + (-Q_{ur} - Q_{dr})/I_z \end{cases}$$

ADRC Control Law Design: A tailored ADRC control law is designed for the roll, pitch, and yaw channels, incorporating a Tracking Differentiator (TD), Extended State Observer (ESO), and Nonlinear State Feedback (NLSEF).



Tracking differentiator (TD):

$$\begin{cases} \dot{\theta}_{d1} = \theta_{d2} \\ \dot{\theta}_{d2} = fhan(\theta_{d1} - \theta_d, \theta_{d2}, r, h_0) \end{cases}$$

Extended State Observer (ESO):

$$\begin{cases} e_{\theta 1} = \theta_{d1}(T) - z_{\theta 1} \\ e_{\theta 2} = \theta_{d2}(T) - z_{\theta 2} \\ u_0(T) = k_1 fal(e_{\theta 1}, \alpha_1, \delta_0) + k_2 fal(e_{\theta 2}, \alpha_2, \delta_0) \\ u(T) = u_0(T) - z_3(T)/b \\ \Delta\delta_{eu} = u(T) \\ \Delta\delta_{ed} = -\sigma_\theta * u(T) \end{cases}$$

Nonlinear State Feedback (NLSEF):

$$\begin{cases} e_{\theta 1} = \theta_{d1}(T) - z_{\theta 1} \\ e_{\theta 2} = \theta_{d2}(T) - z_{\theta 2} \\ u_0(T) = k_1 fal(e_{\theta 1}, \alpha_1, \delta_0) + k_2 fal(e_{\theta 2}, \alpha_2, \delta_0) \\ u(T) = u_0(T) - z_3(T)/b \\ \Delta\delta_{eu} = u(T) \\ \Delta\delta_{ed} = -\sigma_\theta * u(T) \end{cases}$$

Parameter Optimization: An improved particle swarm optimization algorithm is utilized for automatic parameter tuning to enhance control effectiveness.

Optimal Parameters of Active Disturbance Rejection Control Law

Module	parameters	pitch channel r	roll channel	yaw channel
TD	r	0.5850	0.4481	0.6874
ESO	δ	3.0003	0.01	3.1945
	b	42.8526	105.8782	9.1349
	β_1	30.0893	83.8239	3.9438
	β_2	1236.6	882.7060	100
	β_3	2255.8	476.9323	130.0693
NLSEF	δ_0	15.6144	10	0.1
	k_1	6.1934	3.7945	1.0616
	k_2	15.6144	13.0239	0.6874

Results

Comparative simulations between PID and ADRC control laws demonstrate the superior performance of ADRC in terms of response accuracy, speed, and robustness against disturbances.

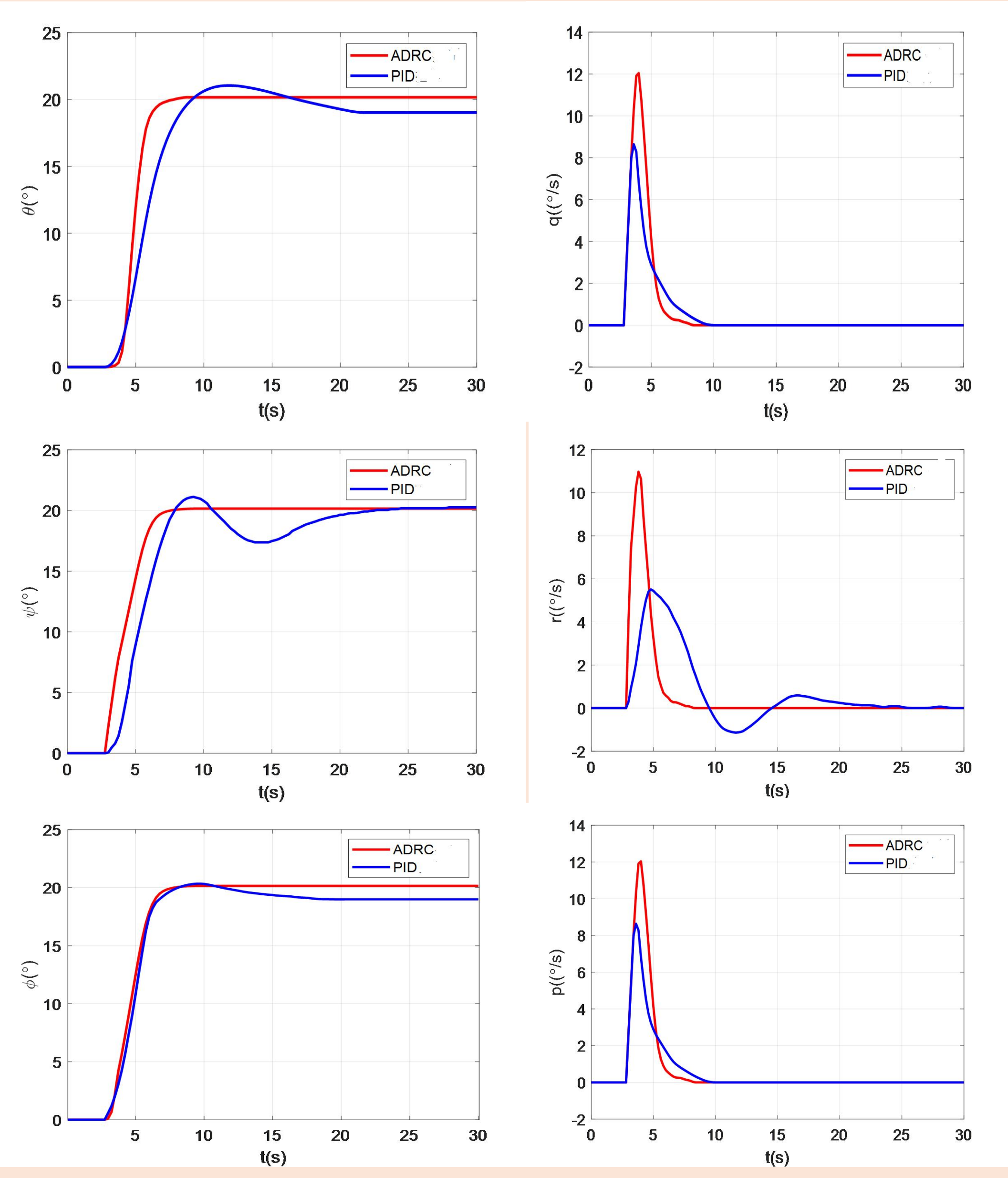


Figure 1. Attitude angle response without interference

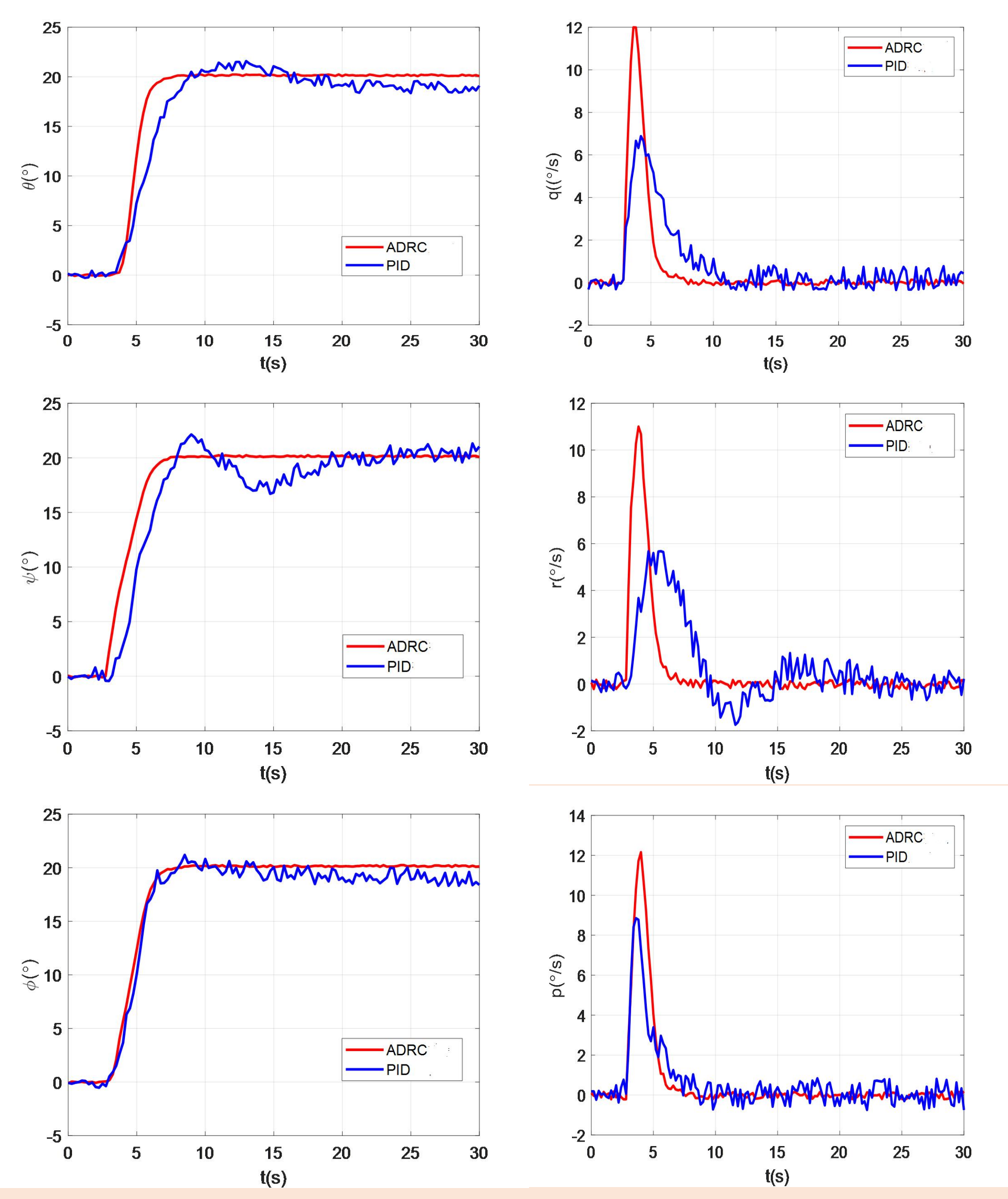


Figure2 Attitude angle response after airflow disturbance

Conclusion

This article adopts an active disturbance rejection controller to design the attitude control of a coaxial unmanned helicopter. In response to the problem of excessive tuning parameters of the active disturbance rejection controller, an improved particle swarm optimization algorithm is used in the parameter optimization process to achieve automatic parameter optimization. The improved particle swarm optimization algorithm has been verified through simulation to have better parameter optimization performance compared to traditional particle swarm optimization algorithms; By comparing the self disturbance rejection attitude controller with the PID attitude controller after tuning parameters through simulation, the simulation results show that the self disturbance rejection control has better dynamic performance and better anti-interference and robustness against external disturbances represented by atmospheric turbulence.

References

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